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Development of an Assessment Model for Flood Risks in Industrial Sectors Considering Climate Change

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Jieun Ryu

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Advisor: Dong Kun Lee

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Jieun Ryu

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Chair	____________________	(Seal)
Vice Chair	____________________	(Seal)
Examiner	____________________	(Seal)
Examiner	____________________	(Seal)
Examiner	____________________	(Seal)

Abstract

Development of an assessment model for flood risks in industrial sectors considering climate change

Jieun Ryu
Interdisciplinary Doctoral Program in Landscape Architecture,
Graduate School, Seoul National University
Supervised by Professor Dong Kun Lee

Recently, damage from meteorological disasters in the urban and industrial sectors has increased as a result of climate change. Notably, flooding damage to urban and industrial facilities from torrential rainfall has significantly affected the national economy, and huge costs are involved in repairing the damage. Since flood damage is expected to increase with climate change, a method for accurately assessing future flood damage due to climate change is required in order to minimize this hazard.

Risk assessment is predominantly used to provide advance responses of damage to businesses from a natural disaster, in this case flooding. Damage from the probable flood is determined based on actual cases of previous damage, and the risk is assessed using probability and damage scales. The risk is assessed by taking into account the applicable hazards and applying them to the vulnerable area. The itself assesses the risk in order to maximize economic profits using an urban flood risk assessment and financial statements. However, for the business to assess the flood risk accurately, the assessment should consider not only the company itself but also its general location, for example, industrial parks, which manage the infrastructure necessary for business activities, such as industrial water, roads, and electricity. Considering this, a comprehensive flood risk assessment is required by the business.

Therefore, in this study, to assess the flood risks according to the climate change, the risk assessment system considering the multiscale is suggested. To do that, first, mesoscale and microscale were defined and the assessment subjects and the spatial range of the assessment subject were established. Second, the assessment methods in each spatial unit were selected. The assessment method can be varied depending on the assessment goal and the spatial range, and the risk assessment in the mesoscale used the concepts of vulnerability and hazard and the risk assessment in the microscale used the concepts of probability and the consequence. Third, the data were built through the site survey, expert consultation, climate scenario, in-depth interview with the interested persons, and by collecting the damage data by the flood in the actual enterprise and industrial park. The flood risk in the enterprise was assessed finally by aggregating them with risk matrix after assessing each risk in the mesoscale and microscale. Since this assessment system considers diverse environments related to the enterprise and the characteristics of the enterprises, it can be used as useful assessment tool to reduce the actual flood risks in the enterprise.

This study suggested the flood risk assessment system in the multiscale and applied it. Considering the business type, four enterprises, which required the flood risk assessment were selected. The selected enterprises are the power plant, the manufacturer of electronic component, the EPS manufacturer, and the pulp and paper manufacturer.

In the mesoscale, the hazard and the vulnerability was assessed based on the index and each assessment results were aggregated to risk matrix after rating them. The indexes were listed from the preceding researches and the vulnerability indexes were selected after consulting and questionnaire survey with experts such as experts of climate change and industry sector, enterprise officers, local government, which controls the enterprises, Human Resources Development Service of Korea, Korea Industrial Complex Corporation. The hazard assessment indexes were selected through the literature review and by collecting the actual damage data by the flood in the industrial park and enterprise. The hazard and the vulnerability were assessed with five grades by industrial park, and the risks of industrial park where four enterprises are located in the Mesoscale were assessed by illustrating the assessment results in the risk matrix. The final assessment results were classified into safe level (1st grade), normal level (2nd grade) and dangerous level (3rd grade). The power plant was assessed as normal level both for present and future. The manufacturer of electronic component was assessed as safe level in the present and the near future and was assessed as normal level in 2050s showing that there will be increase of risk. The EPS manufacturer was assessed as normal level both for present and future, and the pulp and paper manufacturer was assessed as normal level both for present and future.

In the microscale, the flood risks were listed up through the literature review, damage case collection, and three potential risks, which can occur in the enterprise, were selected. For the risks selected, the probability and the consequence were assessed with five grades using the data of in-depth interview with enterprise officers, collected damage data, inundation trace map of the subject area. Each assessed results were classified into safe level (1st grade), normal level (2nd grade) and dangerous level (3rd grade) by illustrating them in the risk matrix. For the power plant, Risk 1, Risk 2 and Risk 3 were assessed as dangerous level, normal level and safe level, respectively. For the manufacturer of electronic component, Risk 1 was assessed as safe level, and Risk 2 and Risk 3 were assessed as normal level. In case of EPS manufacturer, Risk 1, Risk 2 and Risk 3 were assessed as safe level, normal level and dangerous level, respectively. And in case of pulp and manufacturer, Risk 1 and Risk 3 were assessed as safe level and Risk 2 was assessed as dangerous level. All these are the results assessed based on the current status of facilities and the management in the enterprise.

The comprehensive flood risks in the enterprise were assessed by illustrating the assessment results in the microscale and mesoscale in the risk matric again. Although in the mesoscale, the climate change was considered, since in the microscale, it is hard to reflect the changes in the enterprise by the climate change and the investment in the facilities and installations considering the climate change is not certain, it was assessed based on the present. Therefore, in the mesoscale, the present and the future were indicated and the present value in the microscale was applied to each of them. Once the business is established, it is assumed that there will be no change in facilities except for partial repair and replacement; therefore, risk assessment results on the macroscale and microscale are compared within one matrix. For the power plant, Risk 1, Risk 2 and Risk 3 were assessed as dangerous level, normal level and safe level, respectively. For the manufacturer of electronic component, Risk 1 was assessed as safe level, and although Risk 2 and Risk 3 were currently assessed as safe level but were assessed to be changed to normal level in the future. As such, it was observed the change in the enterprise's flood risks according to the future climate change when the enterprise operates the facilities and installations considering the flood with the same criteria as the present.

The data in this study were built by collecting them from the more than two times of in-depth interview with the enterprise officers, damage cases of the enterprise by the flood, damage cases in the area where the enterprise is located, interview with the local government related to the enterprise and various administrative organizations. These data are easy to be used to reduce the damage by determining the degree of flood risks comprehensively, which can occur in the enterprise, In the results of examining the preceding researches, since the enterprise places the priority on the investment to increase the production performance rather than to prepare against the potential natural disaster by the future climate change, The research to assess the industry and the climate change, especially the relations between the enterprise and the climate change has not been sufficient. Therefore, it is expected that the enterprise's flood risk assessment method considering the multiscale would be used for risk management in the long-term aspect of enterprise.

Keywords : Risk, Risk assessment, Risk analysis, flood, Industrial parks, Industry, Mesoscale, Mircoscale, Multiscale risk assessment, enterprise

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1. Introduction

Climate change refers to the overall phenomenon of climate being affected by factors such as energy, industry, transportation, and land use associated with economic activity, as well as by greenhouse gas emissions. The United Nations (1992) defined it as the changes in climate that occur directly and indirectly because of human activity, in addition to natural climate variability. Among the phenomena caused by climate change, flooding occurs most frequently all over the world, and causes the greatest damage (Gaume et al., 2009; Komolafe et al., 2015). In Europe, damage equivalent to €1 million was incurred from 1986 to 2006 (CEA, 2007), and in New York and New Jersey, USA, superstorm Sandy wreaked havoc and caused $60 billion worth of damage in October 2012 (Aerts et al., 2013). In Central Europe, flooding in the Elve and Danube basins incurred damages of approximately €12 billion and dozens of fatalities in June 2013 (Schroter et al., 2015; Munich Re, 2013). Such damage tends to increase gradually (CEA, 2007).

A business is the main agent of industry (Kim, 2014). Not only are the businesses that use raw materials sensitive to climate, but also the governing industries are influenced by climate because of factors such as government policies on climate change (Lee and Kim, 2008). Since the industrial sector has a greater ability to adapt to climate change than other sectors due to higher safety design standards, research has been conducted on the response so far to the regulation of damage mitigation by the government (Ministry of Knowledge Economy, 2012). However, flood damage to businesses is increasing as a result of, among other things, an increased frequency and intensity of rainfall and changes in storm patterns caused by climate change (Rizzi et al., 2016). In Korea, roads and factories were flooded in Ulsan-Mipo Industrial Park and Cheongwon-Noksan Park in 2009, in Bupyeong Park in 2010, and in Gumi National Industrial Park in 2012. It is expected that such damage will increase because of the aging infrastructure and the increased rainfall accompanying climate change (Ryu et al., 2016).

While businesses should consider diverse socioeconomic factors and business types, as well as climate factors (Einarsson and Rausand, 1998; Gasbarro and Pinkes, 2015), they usually do not want to disclose internal information, thus research related to flooding is limited. Previous research has included: evaluations of flood vulnerability reflecting the spatial characteristics of industrial parks and local governments (Ryu et al., 2016); business vulnerability evaluation indexes based on company type by selecting representative businesses within the industrial park (Bae et al., 2013); evaluation of the vulnerability to climate change based on the proportion in the industrial sector, on the local government scale (Kim et al., 2013); research regarding water risks at the company scale as a result of climate change (Park et al., 2015); and evaluation of urban floods according to their spatial scale (Ballesteros-Canovas et al., 2013), rather than considering individual businesses.

However, more comprehensive research is needed in order to consider the regional scale of factors influencing processes important for production activities and climate change. Since climate change has clear regional effects, it should also be considered whether the impacts would be important on the scale of individual businesses. Domestic manufacturing companies are established on individual sites and planned land. Individual sites consist of land for industry development at the discretion of the business, and planned land typically refers to industrial parks (Park, 2010). Since manufacturing occupies 30% of the GDP, and 60% of manufacturing businesses are located in industrial parks, among which the national industrial parks occupy 60%, approximately 10% of the GDP comes from manufacturing in national industrial parks (Park, 2009). The industrial parks have a high concentration of businesses, and they have the advantage of sharing technical information and reducing raw material transport expenses, among other things. However, if climate change results in natural disasters, the ripple effects on the region and the national economy could be severe. In addition, since the impact of climate change on individual businesses differs according to the business type and the processes of individual factories (Gasbaroo and Pinkse, 2015), a comprehensive risk assessment of climate change should consider specific characteristics of each business.

Climate change risks involve an increase in climate-related hazards with time, and damage to people and property (Hay and Mimura, 2010). Flood risk management has the purpose of reducing the flood damage impact to people and property (Kandilioti and Makroponlos, 2012). For risk management strategies, method assessment and management according to flood type and flood risk are needed (Ballesteros-Canovas et al., 2013). The risks can be assessed at multiple scales by selecting the assessment method according to the spatial scale of the assessment subject (Hammond et al., 2015; de Moel et al., 2015). Flood risk can be decreased by reducing either the probability or magnitude of a flood (the hazard), or its consequences (de Moel et al., 2015).

For company flood risk management, the purpose of this study is to suggest and apply risk assessment models at the mesoscale, which is the unit affected by climate. To do this, the mesoscale risks of drought and flooding for all national industrial parks are first assessed. Second, the risks to businesses at the microscale are assessed, considering the characteristics of individual companies. Third, a comprehensive assessment is made of the climate change-induced flood risks to the business by applying the risk assessment results at the mesoscale and microscale, as ranked in the risk matrix. The outcome of this study is an assessment model that can respond to climate change in a flexible manner by providing comprehensive, spatially-relevant information that takes into account the regional climate, geographical characteristics, infrastructure, and flood risk, considering specific characteristics of individual companies.

2. Literature review

2.1. Definitions of risk assessment terminologies

Flood risk has been the focus of the most research in terms of climate change because increased excessive rainfall from climate change causes floods, which in turn causes damage to life and property (Komolafe et al., 2015). In the past, to control flooding, research has mainly focused on the impact and risk of flood hazard (Bubeck et al., 2011). In addition, research has been conducted to prevent damage by flood through flood prevention measures such as levees and dikes (de Moel et al., 2014). However, various countries, including some in Europe, have recently introduced the concept of risk management (Bubeck et al., 2011). Current research is trending more towards assessing risk of flood events and their negative consequences (UNISDR, 2009). This assessment method became a foundation for disaster risk analysis, and flood risk refers to the flood hazard and the vulnerability of the people exposed to floods.

Risk is a concept used in diverse areas (Kim, 2015). Risk is the loss expected from a specific danger in a specific area and reference period (UNDHA, 1993), and can be caused by hazards such as perturbation and stress caused by climate change.

Generally, it is defined as the probability of the occurrence of an unexpected event that causes a disaster or negative results (Smith, 1996; Brooks, 2003; Jones and Boer, 2003). This is a new approach compared to the concept of climate vulnerability assessment, which uses the concepts of climate exposure, sensitivity, and adaptation capability according to the application subject (Turner et al., 2003).

The priority is determined by assessing the possibility of the occurrence of the event, and the potential influence on the assessment subject when the event occurs, through risk assessment. Risk assessment is composed of risk analysis, which identifies the risk, the cause and possibility of the event occurrence, an estimate of the degree of impact, and the risk evaluation. It is necessary to select the risk by considering the vulnerability of the subject to the risk (EMA, 2003; Engemann and Henderson, 2012). The size of the risk is expressed as the probability of event occurrence multiplied by the damage from the occurrence (Brooks et al., 2005). Risks with high occurrence probabilities tend to cause light damage, and risks with low occurrence probabilities tend to cause great damage (Yoon et al., 2012).

Risk assessment for climate change is the process that specifies the risks, which can occur because of climate change, in the socioeconomic aspect, and provides a specific foundation for the factors that should be managed in establishing adaptation policy, which can be very important in adapting to climate change (Kim and Park, 2012). In the 5th report of the IPCC (Intergovernmental Panel on Climate Change), the risk related to climate depends on the interaction of climate-related hazard elements with the exposure of humans and the natural world' s vulnerability and adaptation level.

The assessment method is varied depending on the definition of the risk. If the risk is defined as the degree that the man is exposed to the hazard (Smith, 1996), it can be calculated by multiplying the damage by its probability. In other research, the risk was defined as the product of vulnerability and the hazard (UNDHA, 1992), and in this case, it is calculated as the product of vulnerability and the hazard. Here, the vulnerability refers to the vulnerable area and vulnerable classes, and the hazard refers to the risk itself by the climate change.

Accordingly, as a method to assess flood risk and its potential impact on people, it is assessed using the comprehensive risk, obtained by multiplying the hazard, vulnerability and sum of the risk elements, which is useful for assessing the flood hazard at any regional scale and in any community (Komolafe et al., 2015).

Table 1. Arrangement of risk assessment and analogous terms.

Terminology	Definition	Source
Risk	Risk are commonly probabilistic in nature, relating 1) The probability of occurrence of a hazard that acts to trigger a disaster or series of events with an undesirable outcome 2) the probability of a disaster or outcome, combining the probability of the hazard event with a consideration of the likely consequences of the hazard	1), 2)
Vulnerability	Degree to which a system is susceptible to injury, damage, or harm. It's depends critically on context, and the factors that make a system vulnerable to a hazard will depend on the nature of the system and the type of hazard in question.	6)
Hazard	Probability of occurrence of natural event with a particular intensity at a certain location is defined by the term hazard	5)
Probability	Probability means the likelihood of occurrence of a hazard in a defined period	4)
Consequence	Consequence means direct or indirect damage from natural disaster. Consequences of natural disasters are differentiated into four groups. • direct consequences relate directly to the area and time of the flood event. • indirect consequences are often associated with consequences occurring outside the flooded area, or after the flood event. •Tangible and intangible consequences refer to effects that can be monetized(tangible) and effects that re much more elusive to quantify or even monetize.	4), 7)

Note 1)Brooks (2003) 2)Kim(2015) 3) Kron(2005) 4) Tariq(2013) 5) Hirsch et al.(2015) 6) Brooks et al.(2005) 7) de Model et al.(2015)

2.2. Risk assessment

Risk is the probability of a hazard event, with consideration of the likely consequences of the hazard (Smith, 1996; Stenchion, 1997; Brooks, 2003; Brooks et al., 2005; Leitch, 2010; Merz et al., 2013) (Equation 1). Risk assessment research on the various flood risks and industry sectors applies this concept by multiplying the value of the climate hazard by the value of the vulnerability, as shown below (Equation 2) (Hay and Mimura, 2013; Foudi et al., 2015).

As an important part of disaster risk assessment (Birkmann and Wisner, 2006), the vulnerability assessment identifies the vulnerable factors, assesses the impacts, and evaluates the potential risk by identifying the coping capacity and resilience factor (Merz et al., 2013). Here, the vulnerability is a concept different from the vulnerability assessment referred to by IPCC (2007). Vulnerability, in the 1970s and 1980s, referred to physical fragility (e.g., the possibility of building collapse because of earthquake impact) (Brikmann, 2007). However, recently, vulnerability is defined as the system or unique characteristics that are damaged by the impact of hazard (UN/ISDR, 2004; Merz et al., 2015). The irrecoverable state caused by the negative impacts of hazardous events can be considered as gihg vulnerability(Wisner, 2002). Hazard can be expressed using probability and intensity, and vulnerability can be expressed using susceptibility and the exposure (Tariq, 2013).

Risk is the probability of a hazard event, with consideration of the likely consequences of the hazard (Smith, 1996; Stenchion, 1997; Brooks, 2003; Brooks et al., 2005; Leitch, 2010; Merz et al., 2013) (Equation 1). Risk assessment research on the various flood risks and industry sectors applies this concept by multiplying the value of the climate hazard by the value of the vulnerability, as shown below (Equation 2) (Hay and Mimura, 2013; Foudi et al., 2015). The vulnerability includes the possibility of the risk and the adaptation ability at personal and regional level (Khazai et al., 2013).

Risk = Probability × Consequence …………………equeation1

Risk = Hazard × Vulnerability ………………………equeation2

Vulnerability = Sensitivity − Adaptation …………equeation3

When making an assessment according to the definition of risk, different assessment methods are used depending on the spatial extent and the field (de Moel et al., 2015). In the urban level, there are the researches of analyzing or assessing the vulnerable area through the modeling to assess the actual flood risk in the mesoscale (Ghile et al., 2014). In the microscale, there is the cases of assessing the risk from the area using the depth−damage curve of that area, too (Arrighi et al., 2013;

Lacerda et al., 2014). However, in the industrial area, to consider the infrastructure of where the enterprises are located, the individual enterprise unit is defined as microscale and the scale of industrial park where the enterprises are located as mesoscale.

2.3. Mesoscale risk assessment

2.3.1. Definition of mesoscale

According to the definition of risk, research on the macroscopic aspect of risk assessment is undertaken using the relationship between the hazard and the vulnerability. In the macroscopic scale, the degree of risk can be determined roughly using vulnerability assessment (UNDHA, 1992; Brooks, 2003). In risk assessment, the mesoscale is defined as a region or unit of business type within a country that receives the impact of climate.

When a country is taken as an assessment unit, each country has a different degree of vulnerability to climate change, according to the characteristics of its climate zone. Brooks et al. (2005) assessed the index-based vulnerability of the country as a unit in order to assess the country vulnerability to climate. Winsemius et al. (2013) estimated outflow by running a global hydrological model using the temperature, rainfall, and potential evapotranspiration for the entire globe. The flood risk was assessed by aggregating the socioeconomic indicators in the global inundation extent and depth.

Since geographical conditions can vary within a country, the flood damage is also varied. Ghile et al. (2014) assessed the risk to the infrastructure from climate to determine the size and extent. In the risk assessment for , they focused on vulnerable area assessment, and to identify the vulnerable area, the socio-economic system in the basin was considered. Nhuan et al. (2014) assessed the potentially vulnerability to hazards such as sea level rise, storms, and floods in the coastal region of Vietnam using geographical indicators. As such, the vulnerability assessment is a good method to quickly assess risk at the macro scale.

In countries within the same climate zone, the scale of damage caused by flooding varies according to the characteristics of the business type. Industries that consume large resources experience the greatest impact of climate change and extreme meteorological phenomena (Ford et al., 2010). Gasbarro et al. (2014) asserted that droughts and floods caused by extreme climate impact water use and facilities, product demand and supply, and subsequently, factors such as insurance. Therefore, when building infrastructure for industrial activity, long-term climate conditions, including extreme meteorological phenomena, should be considered (Hallegatte, 2009). As such, to identify climate impact and risk to the industry sector (Ramieri et al., 2011), and to establish countermeasures, research at the regional or local scale is very important (Rizzi et al., 2016).

Table 2. Arrangement of risk assessment and analogous terms.

Terminology	Definition	Source
Macro scale	Risk assessment at nation unit	1),2)
Meso scale	Risk assessment at regional unit	3),4),5)

Note 1)Brooks et al.(2005), 2)Winsemius et al.(2013), 3)Ghile et al.(2014), 4)Nhuan et al.(2014), 5)Ford et al.(2010)

2.3.2. Mesoscale flood risk assessment

Flood risk assessment research at the mesoscale can be classified into research for constructing flood hazard maps or flood vulnerability/risk maps and research to assess risk for areas vulnerable to floods. Additionally, there are various fields of research using vulnerability assessments, to identify areas that would sustain great damage during a flood (Bae and Lee, 2010). As an assessment method to support decision-making, risk assessment is linked to the cost-benefit analysis in risk adaptation (Ballesteros-Canovas et al., 2013).

To reduce the damage caused by flooding, disaster maps or inundation trace maps at the regional scale are provided at the national level. In England, the state provides risk maps for areas that are potentially vulnerable floods developed using a flood risk assessment tool (FHRC, 2011). The German insurance industry provides flood hazard maps by classifying them into five stages according to flood frequency (Kron, 2005). In Korea, inundation trace maps and disaster maps from local governments are compiled and used in decision-making involving measures such as the government's infrastructure damage support.

To analyze the areas vulnerable to flooding, physical or statistical models are used. Rizzi et al. (2016) assessed the sea level rise and storm surge impacts on different types of coastal systems (e.g., beaches, wetlands, hydrological systems) on the Gulf Coast in Tunisia. According to the concept of risk, the assessment was made by classifying the vulnerability and hazards. For the vulnerability, a vulnerability matrix was constructed using DEM, coastlines, and land use, and the hazard was assessed by simulating the sea level rise caused by climate change, and the hazard and the vulnerability were applied in a risk matrix. Ballesteros-Canovas et al. (2013) used hydraulic models (hydraulic, depth-damage functions, and flood loss models) to respond to the flood damage in the research subject areas in advance. As adaptation options, large dams, small dams, tributary streams, and storm tanks were considered, as well as a cost-benefit analysis (CBA). Ghile et al. (2014) drew the annual basin outflow in the subject region using the water resources system modeling for climate change risk assessment in the Nile basin and performed a sensitivity analysis for the elasticity of outflow according to the annual water flow and temperature using past precipitation data. The results were assessed by showing them in a matrix. Cho and Kim (2015) performed a social vulnerability assessment on flood risk by climate change for Incheon City, Korea, based on an index−based statistical model.

As such, there are diverse studies related to floods at the mesoscale, and in the macro or regional scale, there is research that analyzes flood risk using physical or statistical model and damage cost. However, they use methods to easily analyze vulnerable areas considering regional characteristics rather than risk assessment methods based on actual damage and impact.

2.3.3. Mesoscale risk assessment of industrial sectors

At the mesoscale, there are many cases where the industry sector is studied as a type of land use (de Moel et al., 2014). The relationship between industrial business type and climate change is assessed using questionnaire surveys or literature reviews (Ford et al., 2010), or the indirect loss is assessed considering the relationship between the region and the industry, comprehensively focusing on the vulnerability assessment (Khazai et al., 2013).

Industry has been assessed to experience greater damage, compared to other land uses, from climate change phenomena such as floods. When the risks to the industry sector are assessed at the mesoscale, the spatial extent is determined by including some of the traffic areas that are closely associate with the industry. De Model et al.(2015) assessed that in case of the flooding for an event with a return period of 4,000 years, the industrial area comprises only approximately 5% of the total area, but the damage would be approximately 60% of the entire damage amount.

Recently, in relation to the industry sector, there have been more investigations of awareness of the enterprise and industry officials using questionnaire survey methods. Ford et al. (2010) conducted a survey of 42 enterprise officials on the impact of climate change on the mining industry, which is a major industry in Canada, after a conference. From the survey results, the climate factor impact on the mining business and the major risks were analyzed statistically. Gabarro et al. (2014) used the questionnaire survey method to investigate the awareness of the enterprises of the changes in water use caused by climate change.

Khazai et al. (2013) perform an index-based vulnerability assessment considering the socially vulnerable areas and the vulnerable business types simultaneously to assess the socio−economic vulnerability to the hazard. Merz et al. (2015) assessed the disaster risk to natural hazards for the industry sector in Germany at the spatial level. They assessed it according to hazard and the vulnerability by applying the concept of risk to the interdependency of 16 industrial sectors. Ryu et al. (2016) performed an index−based vulnerability assessment for flooding in the eight industrial parks in Korea using, considering the industry sector.

As such, studies on vulnerability and risk assessment considering regional characteristics are undertaken to assess the impacts of recent climate change on the industrial sector. However, research assessing the flood risk in spatial units where enterprises are concentrated, focusing on domestic and overseas industry sectors, is not sufficient. Since, in Korea, the policy that the state fosters industry by building and managing the industrial parks has been implemented, flood risk assessment in such spaces is very important and should include consideration of future climate change.

2.4. Microscale risk assessment

2.4.1. Definition of microscale

The microscale is defined diversely depending on the field. In meteorology, “microscale” is defined temporally and spatially. Temporally, the scale is from seconds to minutes, and temporally, microscale defined as atmospheric movement of less than 1 km. Choi et al. (2016) defined a station as a microscopic unit to analyze the accessibility. Kwon et al(20120 identified the impacts of climate and environmental variables on the habitat of plants to specify microscale environments. De Moel et al. (2015) suggested a multiscale flood risk assessment method and asserted that the microscale can show the spatial resolution of approximately 1-25 m spatially, and has the purpose of suggesting optimized investment using assessment through actual measurement and validation of methodology. In this study, to assess the risk to the industry sector, the microscale is defined as the smallest administrative district unit, local region, or individual enterprise.

In spatial terms, there are studies that assess the risks in local areas. Lacerda et al. (2014) assessed the vulnerability of industrial plants on the coastline of Rio de Janeiro, Brazil, to flooding, and suggested adaptation measures. They diagnosed the vulnerability through analysis, assuming sea level rise according to the climate change scenario, and suggested the establishment of adaptation measures using simulation scenarios for future climate change. Arrighi et al. (2013) and Tavares et al. (2015) also assessed flood risks at the scale of a city or several cities.

Overall research related to business type can also be classified as microscale if it assesses the individual enterprise by relevant business type. Muller et al. (2015) used four physical models to assess the automotive industry in terms of water use, and water risk filter (WRF) can be assessed by the small basin or individual enterprise unit. This study used questionnaires on the physical, reputational, and regulatory risks, composed of 30 questions. Rodrigues et al. (2015) collected accident reports from the subsectors of wood and mattress manufacturing in the furniture industry in Portugal and prepared a risk matrix by collecting data on the enterprise risks using the questionnaire survey method and by analyzing the days when the industry was shut down, and the possibility of such occurrences.

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2.4.2. Microscale flood risk assessment

In Mircoscale, the flood risk is assessed with the flooding area, depth and actual damage amount using the modeling for the city and area. The value fluctuation of the local area and the building by the flooding is considered, too.

Arrighi et al. (2013) used the hydraulic modeling for Mircoscale flood risk estimation within the city. They calculated the vertical value difference of the buildings within the city and performed the flood depth mapping after preparing stage−damage curves according to that and final risk assessment was made by assessing the economic loss after assessing the damage probability. Tavares et al.(2015) performed the vulnerability assessment for the coastline of Portugal considering social factors. They initially drew 126 vulnerability assessment indexes from the 11 municipalities in the coastline and classified them into 8 factors by performing PCA analysis and classified the vulnerability into 5 levels by aggregating them. Yan et al.(2016) performed the vulnerability assessment for Shanghai, China using indexes considering the sea level rise and the storm surges at the same time and to assess the flooding possibility, MIKE21 model, which is the physical hydrological model. They assessed the flood vulnerability for the future climate change by aggregating those two. Model et al.(2015) asserted that the flood risk should be assessed in the multiscale, out of which the flood risk assessment in micro (local) scale, the terrain elevation, hydraulic structures, building location/type/use, etc. are important. Hazard assessment uses the hydraulic modeling and the rainfall-runoff model is used as the input data of hydraulic modeling.

2.4.3. Mesoscale risk assessment for industrial sectors

In the industry sector, the questionnaire survey method is used for enterprises at the microscale to assess the impacts of climate change by business type, since processes vary greatly by enterprise. Risk assessment methods are widely used by insurance companies to calculate insurance premiums. In some enterprises, to reduce the loss by the internal and external factors, profit and loss analysis is performed after designing adaptation options against the possible risks.

The risks can be classified into 13 types according to the stakeholder and the possible risks (Lee and Lee, 2007). Among them, crises caused by climate or natural causes are classified as natural disaster (Coombs, 2000). The research related to enterprise risk assessment can be classified into three categories, as follows. First, there are cases where the enterprise performs self-diagnosis to reduce risk from natural disasters. Second, there is research to assess the risks to the enterprise and industrial facilities of natech disasters (natural disasters triggered by technological disaster) cause by climate, such as severe cold and flooding. Third, there is research to analyze data on damage caused by natural disasters based on insurance calculations as performed by enterprises such as reinsurance companies.

When an enterprise assesses risks in order to reduce damage from natural disasters, they mainly use the questionnaire survey method to reflect the environment and characteristics of the enterprise. The railway safety system in

England prevents accidents by identifying the critical event or hazards to the infrastructure system and equipment introduced by the Safety Bureau through risk assessment. In casual analysis, the precursors of critical events are identified and determined mainly according to component failure data or estimation by experts (RSSB, 2011). In the resulting analysis, the size of the loss caused by the critical event or hazard is estimated (Lee and Jung, 2003). Additionally, climate risk assessment in England uses diverse data based on UKCP09, which is the climate change forecasting report (Kim, 2015). For the risk assessment, qualitative assessments by experts and stakeholders are used. Such qualitative assessments should be consistent with and supplement the scientific rationality (DEFRA, 2012).

Natechs are disasters that occur in series in a complex manner because of the synergistic combination of the impacts of natural disasters with complex technological systems (Kim and Jung, 2015). Natech risk assessments forecast the loss in the enterprise caused by the domino effect and the possible damage to adjacent residents using a scenario assuming the accident (Salzano et al., 2013). Since many enterprises involve factors such as chemical products, international organizations such as the EC and OECD have published reports of industrial infrastructure damage status and hazard management to reduce natech risks (Arellano et al., 2004; Oh, 2014).

The enterprises that spend the most time studying the damage to enterprises and the possibility of natural disaster occurrence are insurance companies. Particularly, reinsurance companies have abundant data on the damage caused by natural disasters (Kron, 2000; Munich Re, 2000). Such reinsurance companies mainly analyze the damage to people (fatalities and injuries) and the overall economic damage due to the disaster because such data becomes the basis of insurance premium calculations.

Enterprise risks have been studied for a long time but since the rapidly changing rainfall rates and temperatures due to recent climate change affects the production activity of enterprises, research on risk assessment based on climate change is increasing. If natech assessments simply assesses the risk of accident caused by natural disasters, since the climate change risk assessment can affect medium- and long-term overall production factors such as processes, employees, and logistic facilities, importance increasing. However, since the characteristics and environment of enterprise processes vary quantitatively by business type, research on climate change risk assessment for individual enterprises in not sufficient.

2.5. Summary

The increase of flood damage by the increase in frequency and intensity of rainfall due to climate change is expected in the industry sector. Enterprises perform production in the plant, but the transportation of raw materials and products, water supply, as well as commuting employees, are affected by climate. Therefore, damage to the enterprise can be assessed precisely by considering the processes of the individual enterprise and the enterprise's locational conditions. The risk refers to the possible hazard from climate change and its impact, and since the appropriate assessment method can be determined based on the actual damage according to the assessment subject, it is the appropriate assessment method to analyze damage in the industry sector caused by climate change.

At the mesoscale, there are studies that assess flood risk in the subject area using physical models or the damage amount by actual land use, or by simply identifying the high risk areas by analyzing the area vulnerable to floods with index-based assessment. At the mesoscale, since the industry sector is very much affected by the diverse geographical, climate and social conditions, there is research that assesses highly vulnerable area based on indexes. Unlike urban areas, the damage caused by actual floods in the industry sector are greatly varied according to the business type, facility scale, and management of the individual enterprise, for which risk assessment research at the mesoscale is limited to vulnerable area analysis or to some business types.

At the microscale, risk assessment is performed for cities using the actual flood damage cases and physical models. In the industry sector, the risk of certain business types is identified by investigating the business type factor that can be affected by the flood, and the degree of damage, using questionnaire surveys from multiple enterprises. However, such studies only end up identifying the flood risks for that business type. Therefore, for climate change flood risk analysis of the enterprise, the main agent of actual production is needed. However, since enterprises generally do not disclose internal data, research on flood risk assessment for individual enterprises are not sufficient because of data limitations.

This study is unique because it considers the mesoscale and microscale to assess comprehensive flood risk of enterprises. Although, at the mesoscale, there are various studies that have assessed the risk of industrial areas as part of a city, they can hardly reflect the characteristics of the industry sector. Since risk assessment at the microscale comprises research on the degree of impact on the business type rather than individual enterprises, it is difficult to reflect the characteristics of individual enterprises. Therefore, to assess flood risk of enterprises, this study suggests a comprehensive risk assessment model considering the mesoscale and microscale.

The increase of flood damage by the increase in frequency and intensity of rainfall due to climate change is expected in the industry sector. Enterprises perform production in the plant, but the transportation of raw materials and products, water supply, as well as commuting employees, are affected by climate. Therefore, damage to the enterprise can be assessed precisely by considering the processes of the individual enterprise and the enterprise's locational conditions. The risk refers to the possible hazard from climate change and its impact, and since the appropriate assessment method can be determined based on the actual damage according to the assessment subject, it is the appropriate assessment method to analyze damage in the industry sector caused by climate change.

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3. Scope and method

3.1. Spatial scope

In the industry sector, the main agent of production is the enterprise, which is located in individual lands or planned lands. Planned lands are industrial parks, designated as national industrial parks, general industrial parks, urban high-tech industrial complexes, and agricultural industrial parks (Article 2-8, Title 1 of Industrial Sites and Development Act, implemented on March 30, 2016 by the Ministry of Land, Infrastructure and Transport). Since Korea emphasizes the fostering of strategic industry within the industrialization policy, aiming at rapid growth of the national economy since the 1960s (Park, 2009), to encourage the growth of industry at the national level, there has been very active management and investment (Kim and Lee, 2012). Since industrial parks are involved a high proportion of production (approximately 68.6%) and export (approximately 80.7%), they are the driving force of the national economy (Korea Industrial Complex enterprise, 2014).

Enterprises use not only plants, but also infrastructure such as roads and ports for activity such as production and sales. Enterprises are thus affected directly by plant flooding due to climate change, but raw material supply, commuting, and product transport are affected by infrastructure flooding. Therefore, to consider the characteristics of the region where the enterprises and infrastructure are located, in this study, the scope was limited to the enterprises located within industrial parks or surrounding areas.

The research subjects are four enterprises located in national industrial parks in Korea (Figure 1). In Korea, national industrial parks have been built since 1960s and to encourage growth in the industry sector at the national level, with active management and investment (Park, 2009; Kim and Lee, 2012). The proportion occupied by the industrial parks in national production and export is approximately 68.6% and 80.7% respectively, thus industrial parks are the driving force of national economic growth (Korea Industrial Complex enterprise, 2014). Therefore, in this study, the scope was limited to enterprises within the national industrial park that the state manages via industrial support facility. Four enterprises were selected, considering the regional characteristics and the representative businesses in Korea: the EPS(Expanded polystyrene) manufacturer located in Asan National Industrial Park (hereafter, AS), the thermal power plant in Gojeong National Industrial Park (hereafter GJ), the electric product manufacturer in Gumi National Industrial Park (hereafter GN), and the pulp and paper manufacturer in Onsan National Industrial Park (hereafter OS).

AS is the industrial park where businesses related to machines and automobiles are concentrated, and was built to accommodate the demand for industrial land by enterprises that have transferred from the capital region. Some of it was constructed on land reclaimed from the sea, and the total area is 17.76㎢. Of the total 245 enterprises, manufacturing businesses related to machines and the petro-chemical industry comprise 118 enterprises (approximately 48%). GJ is the largest power generation park in Korea, built to provide a stable power supply, with a total area of ㎡, and 42 enterprises related to thermal power plants, which manages the 8 power generators located there. GM is an industrial park built to intensively foster the electronic industry, and is composed of two parks. Park #1 contain the electronics, semiconductor and textile businesses. The total area of the park is 24.6 ㎢, and it is located in relatively flat area. Out of approximately 1,923 enterprises, 635 (approximately 33%) are related to electric and electronic businesses, and involve 45.6billion won in production. OS became a heavy chemical industrial park with global competitiveness by attracting the non-ferrous industry, refining and oil storage, and chemical and paper industries, with the policy of fostering them. Although it is surrounded by mountains on three sides, since one side faces the sea, facilitating the use of the port, it is an area preferred by heavy chemical enterprises. The area is 19.765㎢ and out of 290 enterprises, 77% are related to transport equipment and petro-chemical and machinery, achieving 45.3 billion won of production.

To consider the geographical and climatic characteristics of an enterprise, risk assessment was performed on the size of the industrial park where the enterprise is located, and the enterprise risk was assessed for individual enterprises, considering the processes and overall industrial factors.

The target year was set 30 year in the lifespan of facilities and the repair period considered by the enterprise (based on the 2015 power plant facility status at Korea Midland Power Co., Ltd). For the climate scenario, RCP 4.5 and 8.5, provided by Korea Meteorological Administration, were used.

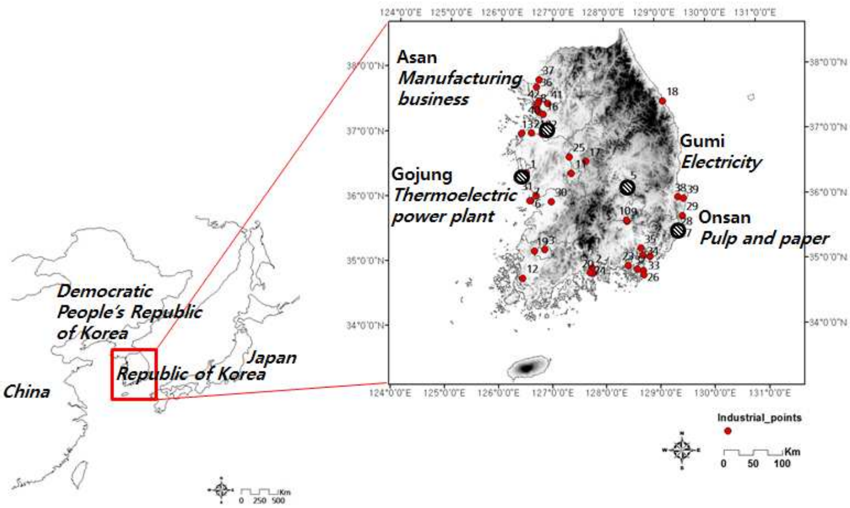


Figure 1. Study area. Grey circles indicate locations of enterprises subject to risk assessment.

3.2. Content scope

This research is limited to floods, which is the climate phenomenon that most clearly causes damage to enterprises (Lee, 2008; Acclimatise, 2009; Choi et al., 2009; Leiter et al., 2009; Cruz and Krausmann, 2013). The content of this research is divided into the development of a multiscale flood risk assessment model for enterprises, and the application of the model. The purpose is to reduce the damage to an enterprise by flooding, considering the microscale risk and the risks in the area where the enterprise and infrastructure is located, and to comprehensively assess the direct impacts of the flood on the enterprise.

The industrial park is the space where individual enterprises and their production spaces are located in a group. All the industrial water, raw materials, product transportation, and production energy that the enterprise uses are supplied through the infrastructure, which is managed by the industrial park. Therefore, if the infrastructure is flooded, production activity in the enterprise may be directly affected. To reduce flood damage to the enterprise, mesoscale flood risk assessment was performed for the industrial parks.

In Korea, if damage occurs to an enterprise from a flood, the affected enterprise should report to the local government and receive part of the recovery cost. However, the degree of damage and the amount of compensation are not managed by the industrial park. In addition, aside from flooding damage to the facilities, losses from delayed production activity, such as commuting delay experienced employees, are difficult to estimate. Therefore, for mesoscale flood risk, an existing vulnerability assessment method using the concepts of hazard and vulnerability was used.

An enterprise' s ability to adapt to floods and the degree of facility and safety management varied depending on the size and business type of the enterprise, and the values of the enterprise owner. Therefore, since collecting objective data on the size and degree of flood damage by the enterprise is difficult, and the number of samples is small, risk assessment using the possibility of flood risk and the concepts of consequence was performed using in-depth interviews with officials.

In this study, flood risk assessment of enterprises was divided into three stages. First, the mesoscale flood risk was assessed considering the characteristics of the area and infrastructure. Second, the microscale risk was assessed considering the environment and the characteristics of the enterprise. Third, the comprehensive risks were assessment by showing the mesoscale and microscale risk assessment results as a matrix.

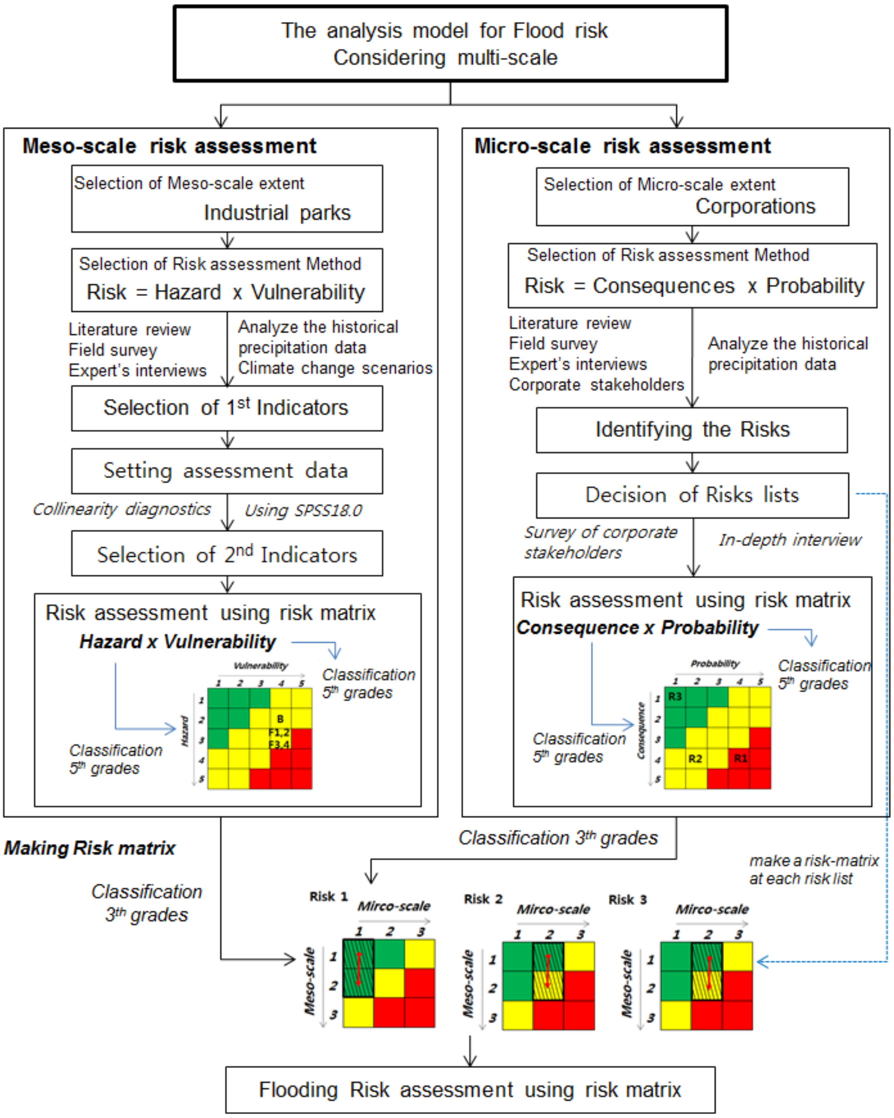


Figure 2. Structure of integrated flood risk assessment framework for enterprises

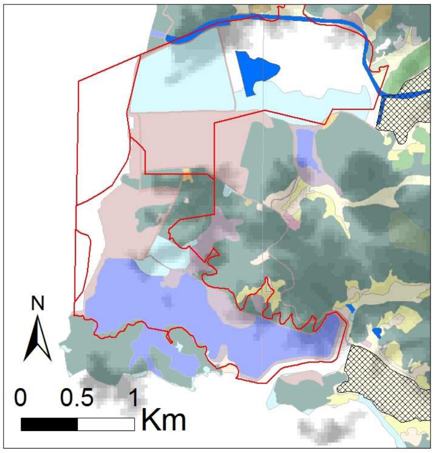
3.3. Method

In enterprises, damage to production activity occurs by the direct and indirect impacts of increased rainfall due to climate change. In this study, to assess the flood risks in the regional environment and the infrastructure, which have indirect impacts on production activity, the mesoscale flood risk comprises the industrial park as the spatial range. To assess the flood risk direct impacting factories, the microscale risk was assessed for individual enterprises. Finally, multiscale risks were assessed by aggregating them in a risk matrix.

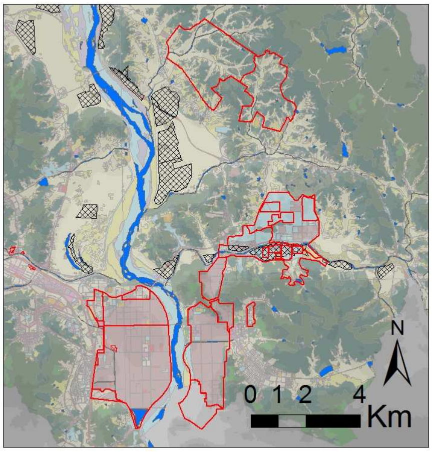
3.3.1. Mesoscale flood risk assessment

1) Selection of mesoscale extent

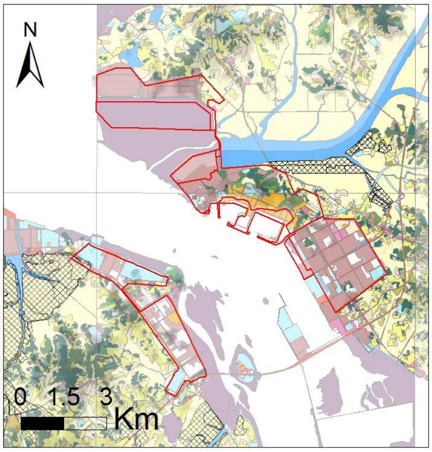
Enterprises are established on individual lands or planned lands. The industrial parks are planned lands, which are divided and developed based on a comprehensive plan for the purpose of business activity, and provide the land, factory, auxiliary facilities, and various services to enterprises on that land (Yoo, 1998). Generally, since industrial parks are formed around large enterprises and various subcontractors, such concentration of production functions specializes in production elements among the same business types, produces diverse external effects enabling the fostering and supply of professional manpower, and has contributed to the national competitiveness (Cho, 2005). The supply of electricity and industrial water is generally managed as a unit of the industrial park. Therefore, to assess flood impact on an enterprise, considering the infrastructure used by the enterprise and the geographical environmental factors, the mesoscale risk was assessed for the industrial park. Figure 3 shows the status of the industrial park where the subject enterprises are located.



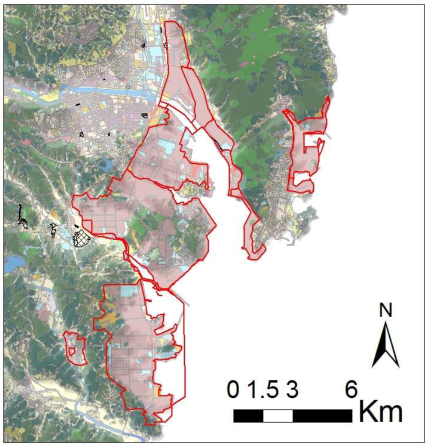
A. Boundary of GJ



B. Boundary of GN



C. Boundary of AS



D. Boundary of US

Figure 3. Status of industrial park. Red lines indicate boundaries of industrial parks. Black hatched areas indicate boundaries of flooded areas.

2) Selection of risk assessment method

At the mesoscale, the flood risk in the industrial park reflecting the characteristics of the regional environment and infrastructure is assessed. In this study, the risk assessment method using the concept of hazard and vulnerability was selected. Since this concept can reflect the characteristics of the regional environment in the macroscopic view, it is mainly used at the mesoscale. The hazard was defined as precipitation, which is the cause of flood damage, and the vulnerability was defined as the degree to which infrastructure and geographical characteristics within the industrial park are vulnerable to the flood.

Since the mesoscale flood risk assessment of the enterprise should consider diverse physical and social variables, flood risk was assessed using a risk matrix by building the index based on the hazard and vulnerability.

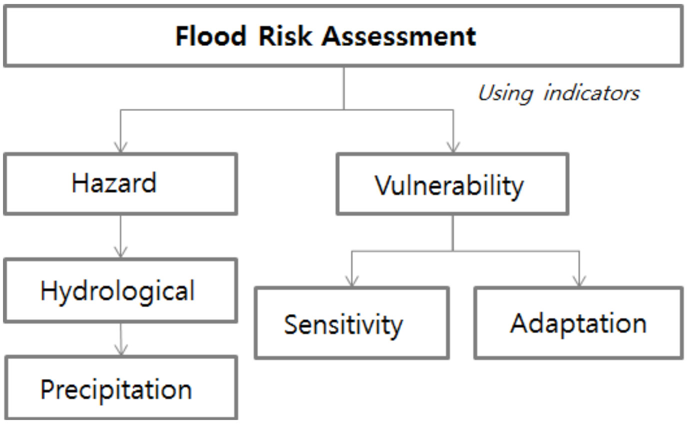


Figure 4. Mesoscale flood risk assessment system.

3) Selection of indexes

To assess the mesoscale flood risk for the industrial park, indexes that fit the assessment subject were selected. The indexes were drawn from literature reviews, expert in-depth interviews (e.g., with the Korean Industrial Complex enterprise, Human Resources Development Service of Korea, local governments, local disaster and safety at local agencies, experts in climate change, enterprise officials), statistical analysis of industrial parks, and enterprise damage data based on precipitation.

From reviews of the existing literature, the number of days with precipitation of more than 80 mm was used as the climate exposure variable in focusing on the flood risk of a city (Bae and Lee, 2010; Son et al., 2011; Kang and Lee, 2012; Shin and Lee, 2014; Ryu et al., 2016). However, since the industry sector was built under a higher safety design standard (Ministry of Knowledge Economy, 2012), it was judged that the precipitation criteria for industrial parks, are different from those of general cities. Therefore, a non-parametric correlation analysis (Spearman method) was performed using actual flooding damage data from the industrial parks and enterprises. The results indicate that days when the daily precipitation was more than 100 mm had strong correlation with the damage amount (correlation coefficient was significant at 0.05 and p-value= 0.697), which can be interpreted as the actual damage amount being increased when the precipitation is greater than 100 mm. Therefore, the number of days when the daily precipitation is greater than 100 mm was selected as the index to assess hazard. Beside of high rainfall intensity, to consider the damage by the rainfall event that the rainfall occurs consecutively, "Number of rainy days more than 5 consecutive days" was used as a variable, too, which is because for the characteristics of soil, when a small amount of rain may fall continuously. The flooding probability is increased as the soil's absorption capability is lowered increasing the outflow. While in the flood risk assessment, both the high intensive rainfall and the consecutive period precipitation possibility are considered by expressing the precipitation possibility with probability. Since in this study, the index-based assessment method was used, beside of rainfall intensity, the concept of duration was used as index to complement the concept of duration.

To determine an index to assess vulnerability, a vulnerability assessment list was first compiled through literature reviews and consultations with experts in 2013. If an index did not match the assessment of the industrial park's infrastructure or regional characteristics, or its data was difficult to compile, it was excluded. The variables drawn were first examined by three climate change experts and officials of the Korea Industrial Complex enterprise, and then by the officer in charge of natural disasters in the Korea Industrial Complex enterprise, city hall, and district office from September to October, 2013.

To assess an industrial park’ s vulnerable to flooding, the vulnerability was assessed in a manner such that the adaptation ability is excluded from the degree susceptibility to flooding. To eliminate the collinearity, a correlation analysis was performed on the variables selected for the assessment index using SPSS18.

In the susceptibility assessment, climate change was not considered in the case of aged buildings, since the flood control capacity (e.g., the size of sewage pipes) is small, and aged pipes have a high rate of leakage, so rainwater treatment is not efficient when flooding occurs (Chu et al., 2010; Goh, 2011, Bae et al., 2013). Therefore, composition time of industrial parks was used as assessment index. Since the possibility of secondary damage (e.g., from landslides) is high during severe rainstorms if the area is close to a forest, industrial park areas within 100 m of a forest was used as an assessment index (Kim et al., 2013 corrected index). It was judged that the closer an industrial park is to a river and coastline, the greater the damage it would incur when the river is flooded (Bae et al., 2013). Since the preliminary disaster impact review, which contains vital data to be submitted, is exempted for factories built reclaimed land soft ground, it was judged that the possibility of flood damage due to climate change can be great (Bae et al., 2013). Average inclination and soil texture in adjacent forests (Kim et al., 2013) was used as the index representing drainage capacity when a severe rainstorm occurs. Since poor strata are likely to reside in areas vulnerable to climate change, and the socially neglected groups are likely to be excluded from participation in adaptation policies or adaptation support, identification of vulnerable groups is vital (Shin and Lee, 2014). In this study, the vulnerable groups were considered to be the large energy consumption businesses, and the number of vulnerable business types within the industrial park was used as the assessment index.

If facilities to supply emergency power exist for when power leaks or is failures are caused by severe rainstorms or typhoons, adaptation ability was judged to be high (Bae et al., 2013). If the number of medical institutions (Chu et al., 2010; Goh, 2011) and the number of stations (Kim and Kim, 2012) are great, it was judged that more rapid responses are possible. It was judged that if the proportion of green zones is higher, the discharge of water is smooth, as the permeable area is wide (Bae et al., 2013; Kim et al., 2013). It was judged that the higher the production performance of an industrial park, the easier it is to invest in damage recovery cost after flooding and sever rainstorms in the industrial park (Linnenluecke et al., 2011). Since the state is building a detention area and retarding basin, which are flood control facilities, and regulates the building of flood control facilities within industrial park recently under construction (Kim et al., 2013), the availability of flood control facilities was selected as an assessment index in this study, as it is considered to be important.

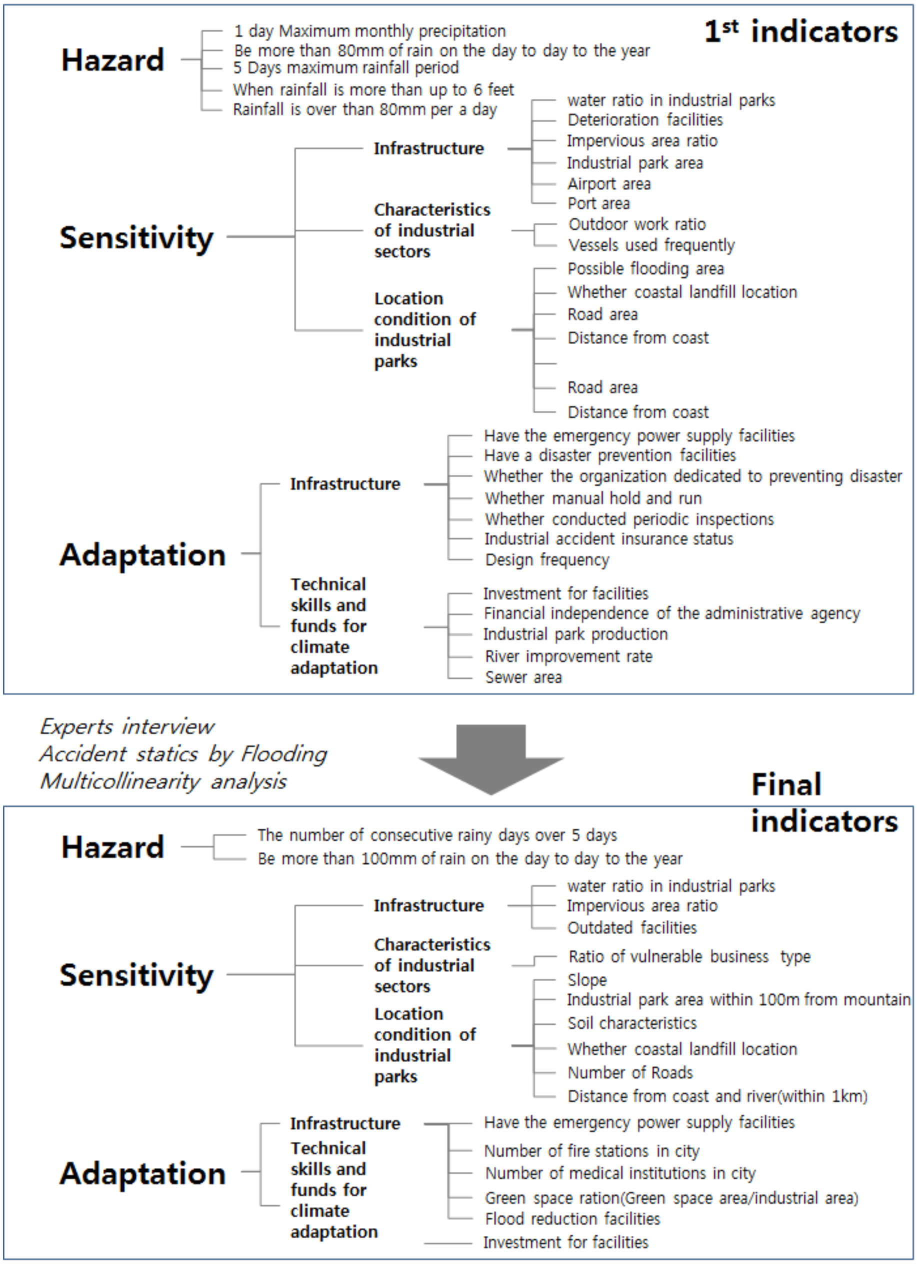


Figure 5. Risk assessment indicators (modified from Ryu et al., 2016)

Indicators constructed using spatial data and social data of industrial parks. Spatial data are made by figure 6 the same way. Industrial parks data were made from the national maps by masking. Social data include only one value of many research categories at each industrial parks.

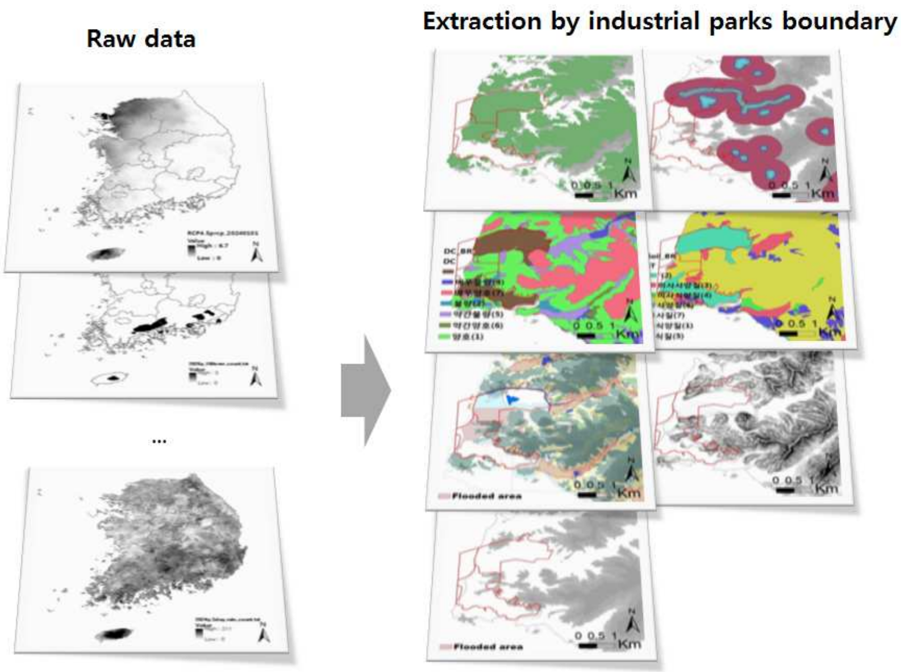


Figure 6. Industrial parks must have a specific value by zonal statistics method of maps

4) Mesoscale risk assessment

To assess the risk in the mesoscale, the indexes corresponded to sensitivity and adaptation to assess the hazard and the vulnerability were selected. And then, The values of hazard and vulnerability by industrial park were drawn finally through the standardization process after building the data by index.

In this study, the vulnerability was calculated with the value subtracted the sensitivity from the adaptation ability. Therefore, to calculate the hazard, sensitivity and adaptation ability, each detailed variables were summed after standardization and passed through the standardization process again and the process is shown in Figure 7.

For the method to assess the sensitivity by each industrial park, the raw data by index are built (S1, S2...), and to calculate the value having different unit, each of them is standardized. The standardized value is referred to as S1', S2'.... The sum of standardized sensitivity indexes is referred to as Ss. And then, to calculate with the hazard and adaptation ability having different unit, Ss is standardized again, which is referred to as Ss'. The method to assess the sensitivity and the method to build the hazard data and the adaptation ability are same.

Data of Sensitivity indicators

S1 S1′ S2 S2′ ⋯ Sn′ Ss Ss′

42 Industrial parks

Industrial parks	S1	S1'	S2	S2'	⋯	Sd	Sd'
Gojung	1020999	0.0265	5	0.0833	⋯	1.9089	0.1594
Gwangyang	4230484	0.1098	9	0.1667	⋯	3.1914	0.5452
Gwangju Science valley	2546427	0.0661	13	0.2500	⋯	3.3223	0.5846
Gumi	3929837	0.1020	35	0.7083	⋯	3.8039	0.7294
Gumi-Hightech	4820809	0.1251	3	0.0417	⋯	3.0317	0.4971
Gunsan	251268.3	0.0065	3	0.0417	⋯	3.3202	0.5839
Gunsan2	1417473	0.0368	3	0.0417	⋯	3.5865	0.6640
Namdong	513998.5	0.0133	22	0.4375	⋯	3.3998	0.6079

S1 : Sensitivity indicators1
S1′ : The standardized index1 values
S2 : Sensitivity indicators2
S2′ : The standardized index2 values
Ss : Sum of standardized values
Ss′ : Standardization of Sn values

$$Ss = \sum_{N=1}^{n} SN'$$

Figure 7. Method to build and assess the sensitivity data to assess vulnerability. The method to draw the adaptation ability and hazard data is same.

To compile the data after selecting the variables, and to define variables as an index from data with different units and characteristics, normalization is vital (Chen et al., 2012; Khazai et al., 2013). Assuming that the original value of index I is i, x_{max} and x_{min} are the maximum and minimum value, respectively of index I (Equation 4). If the upper level index is normalized to 0–1 again after normalizing the values of each individual index, all the values are normalized to 0–1 (Khazai et al., 2013).

$$x_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad \cdots\cdots\cdots\cdots \text{equeation 4}$$

To assess vulnerability, the indexes for sensitivity and adaptation ability are used. After normalizing each substitution index, the sensitivity and the adaptation ability are normalized again after adding them to the substitution indexes. The value of vulnerability is drawn by deducting the adaptation ability from the sensitivity using this value.

To draw the value of a hazard, the climate scenario data provided by the Korea Meteorological Administration is used. In this study, daily precipitation was used for data consistency out of the RCP scenarios provided by the Korea Meteorological Administration. To generate data for the same period, data from RCP 4.5 and 8.5, which cover the same period, were used. To generate data for climate change in the 2030s and 2050s, which are the established target years, considering the life span and repair period of the facilities, the mean value of the data from 2025 to 2034 and the mean value of data from 2045 to 2054 were extracted.

The purpose of risk assessment is to analyze the degree of hazard impacts on the surface and the vulnerability at the relevant points (Nam et al., 2015), and the hazard and vulnerability are shown with a matrix (Zelenakova et al., 2015). To construct the matrix, a process to rate the hazard and vulnerability is needed. Since the rating process normalizes the indexes, to which the individual substitution variables are added after normalizing again, the data can be divided into equal intervals (Kim et al., 2013; Hamdani et al., 2014; Kaliraj et al., 2015; Bing et al., 2016; Chuanglin et al., 2016). In this study, the area, which can be affected by hazard, and the vulnerable areas were divided into five grades, and the area with the lowest hazard impact (least vulnerable) was classified as 1st grade.

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3.3.2. Microscale flood risk assessment

1) Selection of microscale extent

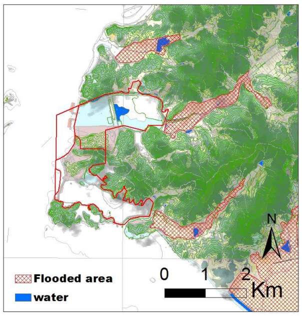
In this study, the flood risk in individual enterprises is examined comprehensively through multiscale risk assessment of the enterprise. If the characteristics of the enterprise region are mesoscale, microscale assessments considering the characteristics of the enterprise will be made from the enterprise. Four industrial parks from different grades were selected in the mesoscale risk assessment, and the flood risk was assessed for a representative enterprise from each park (Table 3).

Table. 3 Enterprises and their locations

enterprises	Location
Electric power station	Go-Jung industrial parks (GJ)
EPS manufacture	A-san industrial parks (AS)
Electronic components manufacture	Gumi industrial parks (GN)
Paper & pulp manufacture	Onsan industrial parks (OS)

The power plant in GN is the largest domestic power plant, and generates power from thermal and steam energy. It is composed of steam power plants (power plants 1 and 2) and a combined−cycle power plant using LNG as fuel, and recently, the Shinboryeong Thermal Power Plant (power plants 7 and 8), which is under construction. A steam power plant generates electricity by converting steam obtained by heating water with bituminous coal into mechanical energy. A combined−cycle power plant generates electricity through gas turbines using heat from exhaust gas first, and then generates power by operating steam turbines with the steam generated by the heat of exhaust gas, achieving power generation efficiency that is approximately 10% higher than thermal power generation. This type of power plant contributes greatly to stabilization of the power supply system because it contaminates the environment little, and has short a down time, as it uses LNG as fuel, but since the prices of raw materials and bituminous coal are very expensive, it generates low electricity during the winter.

Furthermore, the power plant produces steam with high temperature in the power generation process, requiring large amounts of cooling water to lower the temperature, and is thus vulnerable to drought. Additionally, it has higher risk of flooding. Since multiple instances of flooding damage have occurred in the surrounding areas as well as problems with the bituminous coal are stored outside, it was judged that a flood risk assessment is needed.

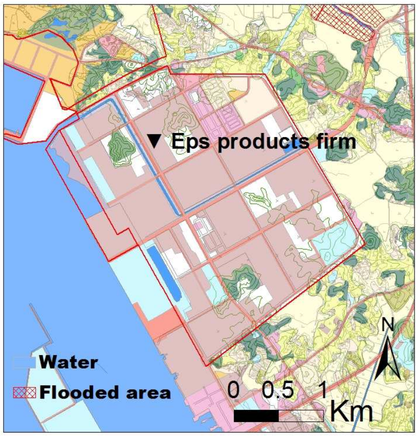


Thermal power	Combined cycle power plant	Small hydro power plant	Sunlight generation	Fuel cell
4,000 MW	1350 MW	7.5 MW	0.5712 MW	0.3 MW
Total 5,358.371MW				

Power plant capacities in GJ

Figure 8. Location of a Power plant in GJ

The EPS manufacturer in AN produces packing materials that reduce shock when packing products, such as thermal insulation materials and sound insulation materials, using expandable polystyrene and expandable polypropylene. The process to produce buffer materials (EPS, EPP), thermal insulation materials (EPS), and sound insulation materials (EPS) are separate, going through phases such as foaming, ageing, forming, drying, and cutting of raw materials. In some processes, constant temperature and humidity must be maintained, and the finished products are stored in the open air, under shade. Therefore, since the value of the product can be reduced or swept away by strong winds or floods, it was selected as enterprise subject to flood risk assessment.



EPS Buffer materials Process
Stock raw material->Forming->Mature->Molding->dry->packing->store product/storage->Outgoing inspection

Figure 9. Location of an EPS manufacturer in OS

The electronic component manufacturer located in GN produces packaging substrate and camera modules. Since temperature and humidity control is important for electronic products, it uses clean rooms where constant temperature and humidity can be maintained. Although no direct flood damage has occurred to the overall processes, since flooding damage occurred in some areas in the industrial park where the enterprise is located in 2007 and 2012, it needs to prepare for disaster by the flood. In addition, since the subject enterprise operates processes where temperature and humidity must be maintained constantly, flood risk assessment is needed for efficient production.

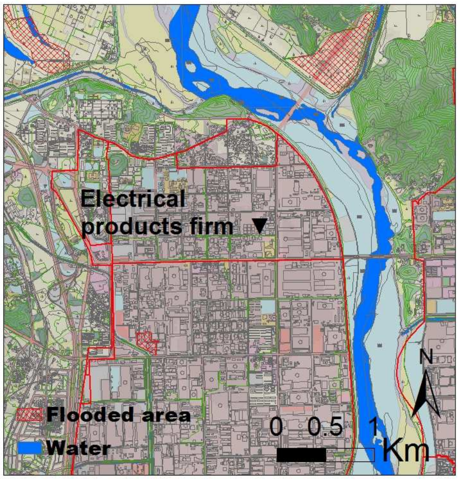


Figure 10. Location of manufacturer of electronic components in GN

Pulp manufacturing in OS can be divided into the pulp process, in which wood chips are turned into pulp, and the paper making process, which makes paper by transferring pulp from the prior phase to the paper machine. Since it uses a large amount of industrial water in the stage of separating lignin and cellulose from the wood chips, it is highly vulnerable to drought. The pulp and paper manufacturer is also vulnerable to flooding. Since the raw materials and products are susceptible to humidity and are stored in the open air, it was selected as an assessment subject, as great damage can be incurred when flooding occurs.

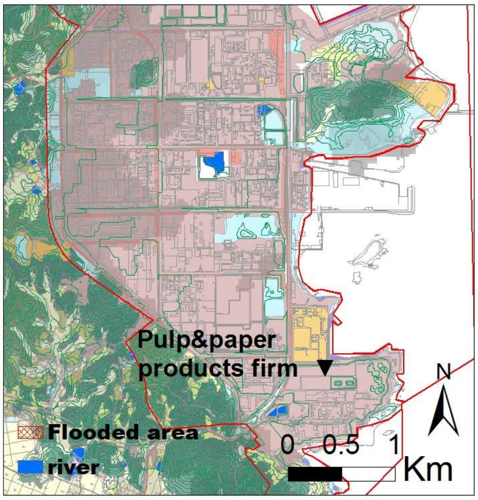


Figure 11. Location of a Pulp and paper manufacture in OS

2) Selection of risk assessment method

Risk is assessed using the concept of probability and consequence (Ortwin Renn, 1998) or hazard and vulnerability. In this study, to assess the mesoscale risk, the concept of probability and consequence was used. This concept can assess direct risk of flooding by considering the local environment and characteristics of the environment or region in the microscopic view. The probability was defined as the probability that a flood can occur in the enterprise, and the consequence was defined as the size and impact of the damage caused by the flood.

The probability of the risk is determined based on the accumulated data and experience, and the risk is assessed by aggregating the degree of impact after predicting it (Kang et al., 2010). Since the accuracy of the risk assessment is degraded when the data and the experience from the past to determine the probability and the intensity of the impact are insufficient, expert questionnaires or the in-depth interviews are used. Research using expert opinions play the role of objective data in the actual problem and the impact occurred in the project. Park et al. (2015) assessed the industrial water supply risk according to the size of enterprise, with climate change, through a questionnaire survey. As such, when the objective and quantitative data are not sufficient, or when it is difficult to apply one methodology, risk assessment using expert in-depth interviews has been performed (Bing et al., 1999; Wang et al., 2000; Kartam et al., 2001).

Particularly, since in the industry sector, processes vary by enterprise, even in the same business, it is difficult to make a uniform assessment. Therefore, it is necessary to identify the situation of individual enterprises through in-depth interviews or questionnaire surveys with enterprise officers and experts, and to analyze and assess the actual risk of the enterprise.

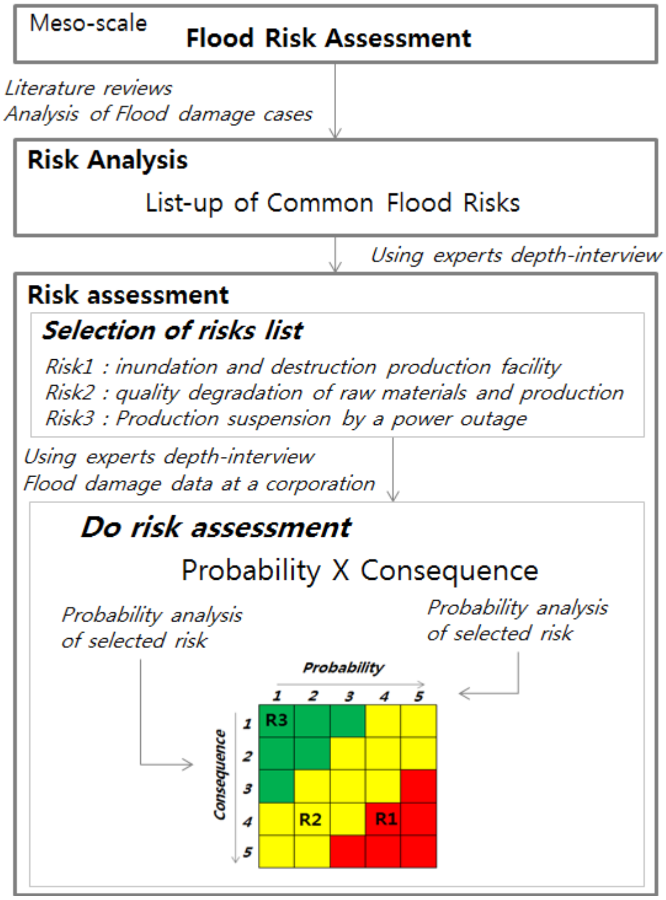


Figure 12. Microscale risk assessment method

3) Risk analysis

To assess the risk, reports on the impact of climate change, on which the risk list was based, were examined. The risk list used in this study was prepared and examined by referring to the risk list in the industry sector from the risk assessment of climate change in England (DEFRA, 2012), and by reviewing domestic and overseas reports related to climate change, such as the First National Climate Change Adaptation Measure (collaboration of related agencies, 2010), Korea Climate Change Assessment Report (National Institute of Environmental Research at Ministry of Environment, 2010), and Climate Change Vulnerability Map by Sector (National Institute of Environmental Research at Ministry of Environment, 2012), and by performing field surveys (six enterprises in the three businesses of electric and electronic, automotive and steel industries, and the local governments, were visited from September to October, 2013).

To ensure that the risks fit the characteristics of each enterprise, a in-depth interview was conducted vial e-mail and meeting, involving the officers of the safety management departments of the pulp and paper manufacturer, EPS manufacturer, electronic component manufacturer, and power plant. This method makes the enterprise prepare a risk list, and was performed as a preliminary survey to establish the risk list prior to the risk assessment. All the risk factors can be collected through interviews with expert groups (Cha and Shin, 2006) and initially, approximately 20 flood risks were drawn (Table 4). When drawing the risk list, factors such employees, traffic and transportation facilities, processes, locations, and markets were considered.

Table 4. First risk list from literature reviews, field surveys and pretests

Categories	Flood risks list
Transportation & Logistics	Road flooding and collapse
	Collapse of road slope and soil erosion
	Transportation vehicle flooding and damage by the typhoon and rain storm
	Raw materials are swept away and damaged during the severe rain storm
	Road congestion
	Damage to the product transportation facilities
	Probability of traffic accident (road and railroad) is increased greatly by the flooding damage
Production	Flooding and collapse of production facilities by the typhoon
	Various tools, materials and large equipment damage and turnover concerns
	Increased possibility of building collapse by the strong wind, severe rain storm. etc.
	Interruption of power supply by the power plant and substation damage (paralysis of the production system)
	Increased risk of damage to street furniture
	Damage to the water treatment plant
	Runoff of contaminated water by the flood
	When the outdoor temperature is dropped by the severe rain storm for extended period of time, additional energy consumption is increased to maintain the temperature
	Quality of raw materials and finished products is degraded by the increase of humidity
	Increase of possibility of mixed discharge of waste dueto flooding
	Damage and collapse of waste treatment facilities by the typhoon and flood
Workers	Increase of worker mortality by the facility collapse and death from electric shock, etc.
	Great increase of injury by thunderstroke, etc
	Possibility of mental disorder in the worker(stress, etc after trauma)

Categories	Flood risks list
	Unable to perform outdoor tasks
Location	Increase of probability of flood damage when the flood is overlapped with sea level of high tide
	Greatly increased the damage due to aged drainage of inner basin
	Probability of flooding inside of workplace and adjacent coastline
Finance	Increase of the human and property insurance premium for the flood
	Increase of recovery cost of damaged facility
	Additional transportation expenses by the problem supply due to infrastructures
	Indemnity claim by the non-delivery
Market	Greatly increased the possibility of occur the damage to other enterprises related to the product production
	Degrade the product quality

4) Risk assessment

In the field survey, the final risks were drawn through in-depth interviews with the officials of enterprises (a total four visits to the three enterprises of pulp and paper, power generation, and EPS manufacturing from October to December of 2015) to reflect the risk list according to the characteristics of the enterprise's business type (Table 5).

The purpose of assessing risks is to determine the management priority of the risk factor, and they were assessed by multiplying the probability by the consequence, which is a simple technique to apply it to the field. The criteria to assess the probability and impact of the risks were drawn by examining preceding domestic and overseas studies and flood damage cases in the enterprise. The criteria were classified as shown in Table 5 and Table 6 (UKCP09).

Table 5. Risk Probability Assessment Criteria

Score	Risk probability	Probability of UKCP09	IPCC/ UKCIP	Considering climate change
5 (VH)	Occur periodically. Occur every year. Occur frequently	Less than 90% /Year	Probability to occur within a year is very high	There exists actual damage (various cases within 5 years) Damage and recovery cost are incurred
4(H)	There is record that is has occurred more than once and the recurrence probability is high. Occur averagely every 2 ~ 3 years	Less than 66% /Year	Do not occur every year	There exists actual damage(various cases within 10 years) No damage and recovery cost have been recorded
3 (M)	Frequency is low or there is a record of occurrence although it is limited locally and recurrence is possible Occurred at least once during past 10 years	Less than 33% /Year	Probability to occur is low within a year	Damage in the past was recorded Considering geographical location and environment, it is judged that the probability is sufficient
2 (L)	It is possible to occur although recently it has not occurred. It	Less than 10%/Year	Probability to occur within a year is	Damage in the past was not recorded but considering

Score	Risk probability	Probability of UKCP09	IPCC/ UKCIP	Considering climate change
	is expected that it will not occur within 10 years		very low	geographical location and environment, it is judged that the probability is existed.
1 (VL)	It is possibile to occur in the worst situation. It is expected that it will not occur within 100 years	Less than 1% /year	The probability to occur within a year is exceptionally low	No damage occurred in the past and the probability is low

UKCP09: UK Climate projection 2009

To assess each consequence of the risk items, questionnaire surveys were conducted involving the enterprise officials according to the classification criteria. A checklist was made based on the risk list prepared for the production, logistic, worker, land, and finance areas having impact on the production of each enterprise, and five enterprise officials were asked to assess them by rating them with a five-point scale.

The probability of the risk items was analyzed by examining the values obtained through the questionnaire surveys and the flooding and destruction of production facilities, and the quality degradation in the raw materials and finished product were selected as the final risk. The error was reduced through a second round of group discussions after constructing a risk value questionnaire survey using a checklist.

Since the purpose of this study is to analyze the degree of influence climate change has on individual enterprises, distribution of the questionnaire surveys was limited to staff members who have abundant experience in the related fields, such as environmental safety and facility management, in the relevant enterprise (Cha and Shin, 2006).

Table 6. Risk strength assessment item and rating criteria.

	Profit-making	**Stable order winning**	**Stable supply of materials and tools**	**Human re resources**	**Compliance with process**
5 points (very risky)	No profit	Did not achieve the goal	Supply is Interrupted	Manpower vacuum	suspended
4 points (risky)	Not achieve the goal	Not achieve the goal	Supply is delayed for long period of time	Not sufficient for a long period of time	Supply is delayed for long period of time
3 points (normal)	Achieved the goal	Achieved the goal	Supply is delayed	Not sufficient for short period of time	Process is delayed
2 points (not risky)	Achieved Partially exceeding the goal	Achieved Partially exceeding the goal	Supply is delayed for short period of time	Slightly problem	Process is delayed for short period of time
1 point (not very risky)	Achieved exceeding the goal	Achieved exceeding the goal	Stably supplied	Smooth	Achieved the process

To assess the flood risk in the enterprise due to climate change, in-depth interview were conducted, presenting the probability of being affected by climate, based on precipitation. The microscale risk was assessed by constructing the probability and consequences from the three risks drawn.

Drawing the in-depth interview and damage cases to the matrix by aggregating them based in the consequence criteria suggested in Table 6 and the probability criteria suggested in Table 7, is shown in below figure. If each probability and the consequence are illustrated with the coordinates by risk item taking the probability as X-axis and the consequence as Y-axis by rating them into 5 grades, the risk 1 is corresponded to risk rating in the risk matrix in Figure 13.

In this study, the risks of the flood commonly great for the enterprise were drawn and that item by enterprise was assessed and since the probability and the degree of impact by risk are different, the assessment results are drawn with 3 risk matrixes.

Since the risk matrix classified the consequence and the probability into 5 grades, X-axis and Y-axis are classified to 5 grades each, and the right bottom was classified into dangerous level, left top into safe level and the other spaces were classified into normal level.

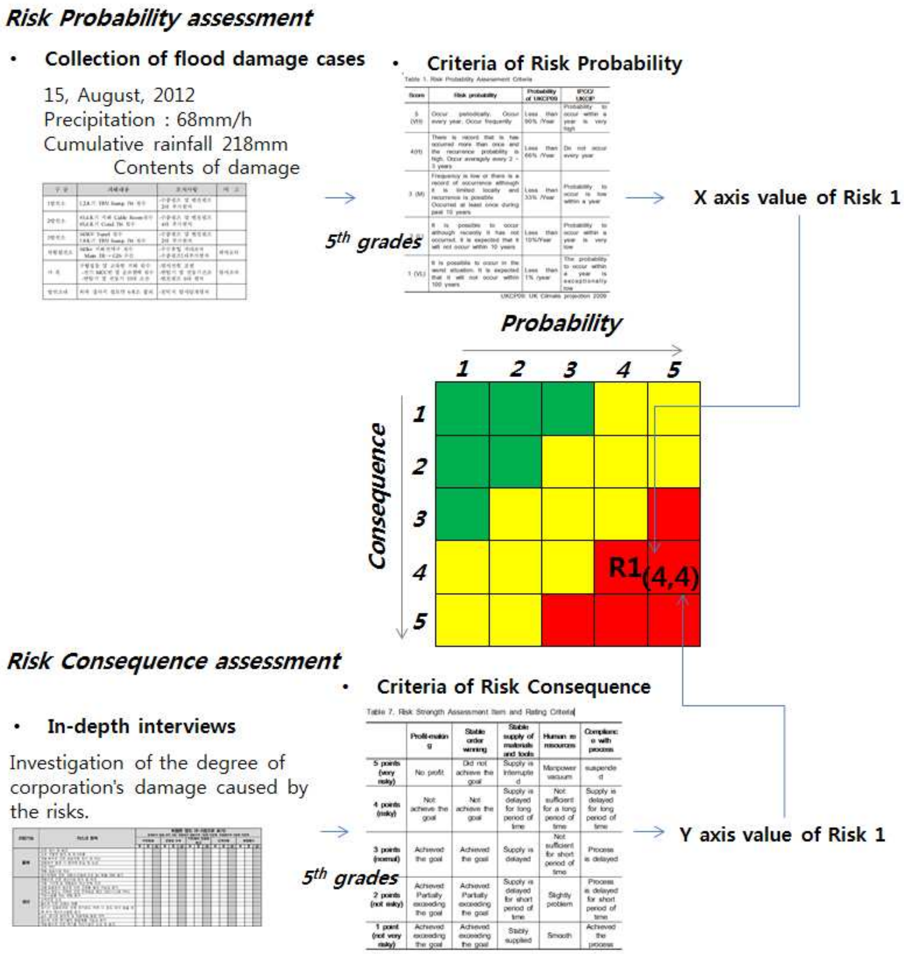


Figure 13. Methods making risk matrix using results of risk consequence and risk probability

3.3.3. Multiscale integrated flood risk assessments

To assess the flood risk of the enterprises comprehensively, the mesoscale and microscale risk assessments were aggregated in a risk matrix. The results of rating the industrial parks at the mesoscale were taken as one axis, and the results of rating the enterprises at the microscale were taken as the other axis, and the point where the two axes intersect was taken as the final risk. The final risks can be classified into three grades of dangerous, normal, and safe, based on the intersection of two results.

Since the mesoscale considers the climate change scenarios, the changes in the flood risk from the present (B) to future (F1, F2, F3 and F4) were assessed using hazard and vulnerability. Since the assessment results can be expressed like coordinates depending on each value of vulnerability and hazard, they can be illustrated in the matrix. They can be classified again into safe level, normal level and dangerous level divided in the matrix based on the illustration results.

In the microscale, the current situation of enterprise is reflected. Since the assessment was made according to the criteria using the in-depth interview with enterprise officers and the data of damage cases in the actual enterprise by the flood, these assessment results are based on the flood experiences in the past and the present. The mesoscale considers the future but since the microscale is based on the present, the spatial scale is not coincided. However, for the characteristics of industry sector, once the enterprise completes the plant and starts the production activities, the situation that the entire plant is constructed again by the climate change in a near future like 30 or 50 years rarely happens and the in-service span of the plant is extended through the partial repair or replacement. Therefore, assuming that the current installations are same in the future, it is judged that the comparison with same matrix is possible. Therefore, the risk assessment results in the microscale were illustrated in the risk matrix and were classified into 3 grades (safe level, normal level and dangerous level).

In the enterprise, the flood risks not only by the facility management and situation but also by the locational condition exist. The flood damage occurs in the enterprise by the enterprise itself such as preparation against the flood in the infrastructures used by enterprise with the region and diverse impacts of surrounding environment. Therefore, it was judged that these parts need be considered comprehensively, and in the locational aspect, the flood risks in the mesoscale and in the aspect of enterprise, the flood risks in the microscale were assessed. The assessment results in two scale were aggregated by illustrating in one risk matrix. Since this is the assessment results by standardizing each of them. Although the risk assessment results in the locational aspect and the risk assessment results in the aspect of enterprise do not have same meaning, it was judged that they can be illustrated in one matrix.

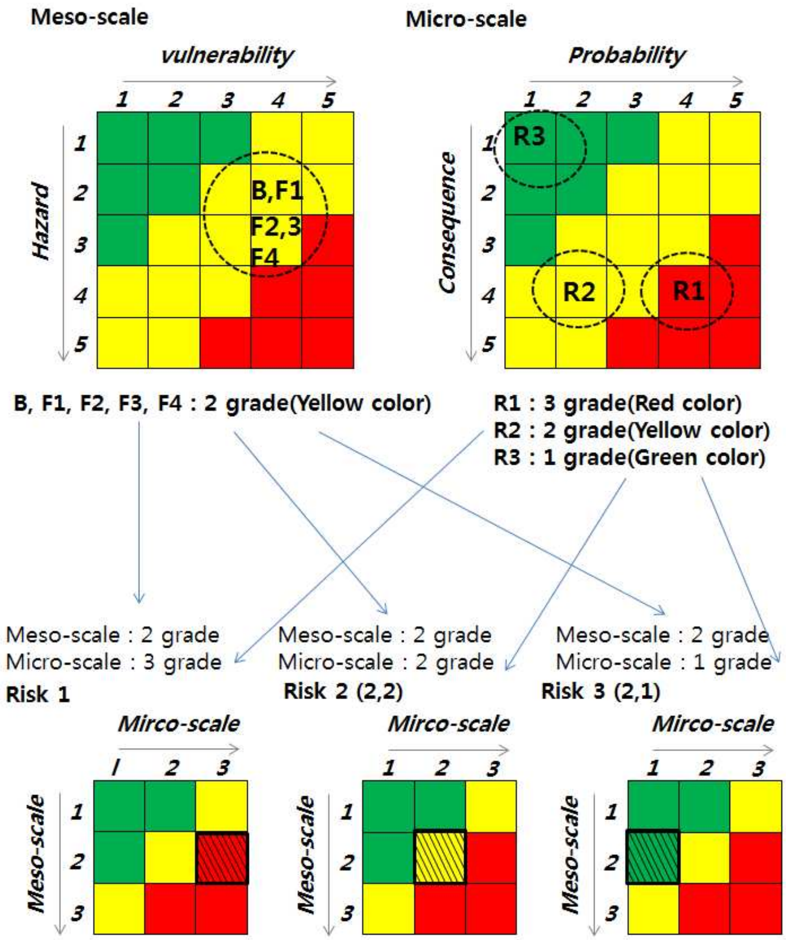


Figure 14. The risk assessment results in the mesoscale by risk item are classified into 3 levels and the risk assessment results in the microscale by risk item are classified into 3 levels. And then, they are classified into 3 levels by aggregating the risk assessment results in the microscale and the risk assessment results in the mesoscale illustrated in the risk matrix in the form of coordinates in X-axis and Y-axis. In the mesoscale, B refers to the present, F1 to 2030s in the climate scenario RCP 4.5, F2 to 2050s of same scenario, F3 to 2030s in the climate change scenario RCP 8.5 and F4 refers to 2050s in the same scenario. In the microscale, r1, R2 and R3 refer to each risk item.

4. Results and discussion

4.1. Mesoscale risk assessment

1) Result of Hazard

Korean Meteorological Administration constructs scenarios by assuming a climate trend using the meteorological observation data from the past, and provides four scenarios from modeling, based on the assumptions. In this study, hazard was assessed based on the index using the RCP 4.5 and 8.5 scenarios. As a results of analyzing the correlation between precipitation and the degree of damage and damage area in industrial regions across the country on days when flooding occurred, daily precipitation of more than 100 mm was found to be significant. Therefore, the number of days with more than 100 mm of precipitation and more than five consecutive days of precipitation was used as the assessment index, thus considering both the intensity and frequency of rainfall.

According to the climate change scenario, the precipitation in our country shows gradually increasing trend from 2000 to 2100. According to the climate change scenario RCP 4.5, the average precipitation in Korean peninsula later half of 21th century is increased by 6.2% during the first of three decades (2011~2040), by 10.5% during the second three decades (2041~2070) and by 16.0% during the third three decades (2071~2100). In scenario

RCP 8.5, it is increased by 3.3% during the first three decades, by 15.5% during the second three decades and by 17.6% during the third three decades. Such pattern of climate change shows the difference in the precipitation increase/decrease according to the model of each scenario. The precipitation is expected to show the non-lineal change during the 21st century by the long-period variability but the warm climate will cause overall change in the precipitation regardless of scenario (Korea Meteorological Administration, 2012).

In the results of Kim et al (2012)'s analysis on the vulnerability for entire country in the aspect of flood control out of the water management, the vulnerability showed the trend that it is increased by 2050s and decreased in 2100. In the results of Han et al (2012)'s assessment on the vulnerability of the infrastructure, the vulnerability in some capital region and the some Jeollado region is increased from 2020s to 2050s but increase greatly in the capital region and Gangwon-do region in 2100s. As such, since the research results using precipitation by region, target years, and scenario show the difference, it is necessary to consider uncertainty using multiple climate change scenario. However, in this study, HadGEM3-RA model was used out of the RCP 4.5 and 8.5 sceanrios provided by Korea Meteorological Administration because the detailed South Korea ensemble weather data provides only one model of HadGEM3-RA. Therefore, this study has limitation that it is hard to consider the uncertainty. In the research related to climate, the research on the uncertainty has been performed continuously (Georgakakos, 1992; Ferraris et al., 2002) but it is hard to exclude the uncertainty completely and recently diverse approaches are attempted to reduce the uncertainty (Lee et al., 201). Therefore, related to this study, the research to verify the range of risk through the analysis using the multiple climate scenario is needed.

In the results of analyzing the precipitation data using the number of raining days more than 100mm/day as an index, the day having annual precipitation more than 100mm, was currently represented as average 1.1 day across the country, and in the future (2030s and 2050s), it was analyzed as 0.1~0.2 day. it showed the great deviation by area and currently Geoje area has annual average 2.2 days representing highest frequency. In 2030s, the frequency of raining more than 100mm is the highest in Gwangyang area showing annual average 0.5 day (RCP 4.5 scenario) and 1.2 days (RCP 8.5 scenario). In 2050s, in the RCP 4.5 scenario, Incheon, Yeonsu-gu area is annual average 0.4 day representing highest frequency of raining more than 100mm and in RCP 8.5 scenario, Gwanyang area is highest with 0.5 day.

In the assessment using the index of the number of days with more than 100 mm of precipitation, the frequency appeared higher in the present than in the future (the 2030s and 2050s). This means that the number of rainy days is reduced in the future (the 2030s and 2050s) compared to the present because the precipitation pattern in the future is different (Lee et al., 2013).

Although currently, the days of raining more than 5 days consecutively show the distribution from 1.7 times to 7 times, while in a near future (2030s), it occurs 53 times the lowest in Sihwa area, Gyeonggi-do and 104.4 times the highest in Geoje area, Gyeongnam, in RCP 8.5 scenario, it was analyzed that it will occur 52.6 times the lowest in Paju, Gyeonggi-do and 111.3 times the highest in Geoje area, Gyeongnam. In Figure 14, the frequency of five consecutive rainy days was found to increase greatly in the future compared to the present. Although currently, the risk is at the 1st grade level, as the number of consecutive rainy days is small, the risk is increased to the 3rd, 4th,and grade in almost every industrial park in the future (the 2030s and 2050s). That is, analysis showed that the number of days with more than 100 mm of precipitation in the future (the 2030s and 2050s) would be small, but the number of consecutive rainy days would be increased when there is rainfall. Particularly, Gwangyang National Industrial Park (#2) was analyzed to have the highest grade of risk, now, and its frequency would be reduced to the 3rd grade and 1st grade in the future. The Gwangyang area has average precipitation of , higher than the national average precipitation, and higher average humidity based on normal years. Since local torrential rainfall occurs intermittently and is located close to the coastline, if the highest tide and local torrential rainfall occur at the same time, great damage could occur to the region' s enterprises. Daebul National Industrial Park in Jeollanam-do is currently an area with the least number of days with 100 mm precipitation, and this tendency was determined to be maintained in the future. Mokpo, Muanssss, the Yeongam area, and Jeonbuk, where Daebul National Industrial park is located, have relatively low precipitation compared to other areas, and lower precipitation than the national average based on normal years (1981-2010). However, the duration of rainy days was relatively longer, with 119 days of precipitation in 2015. In the analysis results of this study, the precipitation was mostly less than 100 mm, showing that the rainy days have long duration, but the rainfall intensity is low. Research by Han et al. (2011) indicated that in the infrastructure vulnerability assessment by the local governments, Jeollabuk-do has very low probability of flooding.

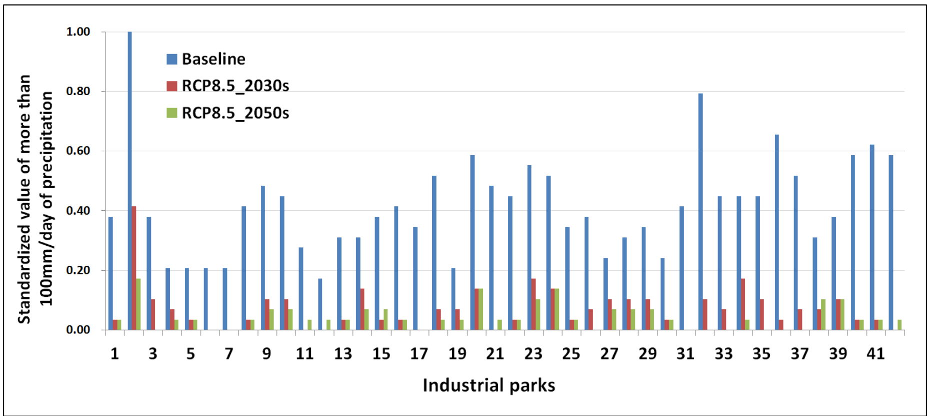


Figure 15. Standardized value of Number of Days with Precipitation more than 100mm by Industrial Park according to Climate Change Scenario (RCP 8.5 Scenario)

Comparing the industrial parks where the enterprises subject to research are located, the number of days with more than 100 mm precipitation in all of four industrial parks appear to be reduced in the future compared to the present, as shown in Table 8. This does not indicate reduction of precipitation, but can be interpreted to indicate that the rainfall intensity will increase. The Korea Meteorological Administration has announced that analysis of precipitation over the last 50 years in Korea indicated that the frequency of rainfall would be reduced, but the intensity would be increased, which will in turn result in increased probability of floods and droughts (Bae et al., 2008). Therefore, it is difficult to assess hazard using only the number of days with 100 mm of precipitation, with such changes in precipitation patterns. Therefore, to take rainfall intensity into account, it was determined to consider rainfall events comprehensively using the frequency of five consecutive rainy days as the index.

Analysis indicated that the frequency of occurrence of five consecutive rainy days using the scenario of climate change, would be increased in the future, as shown in Figure 15. Particularly, Small Resources Reserve Park (20), Okpo National Industrial Park (26), Jukdo National Industrial Park (32), Jisepo Resources Reserve Park (33), and Pohang Blue Valley (39) have high probability of rain falling for more than five consecutive days in the future. Jukdo National Park and Jisepo

Resources Reserve Park, located in Geoje-do, were analyzed to have high probability of such rainfall in the future (2030s and 2050s) both in RCP 4.5 and 8.5. Particularly, the precipitation in the Geoje-do area during normal years (1981-2010) is 2007.3 mm, much higher than the national annual average precipitation. Since in the future, analysis indicated that not only the precipitation but also the frequency of more than five days of rainfall occurring would increase, the industrial parks and enterprises should assess risks in order to be prepared.

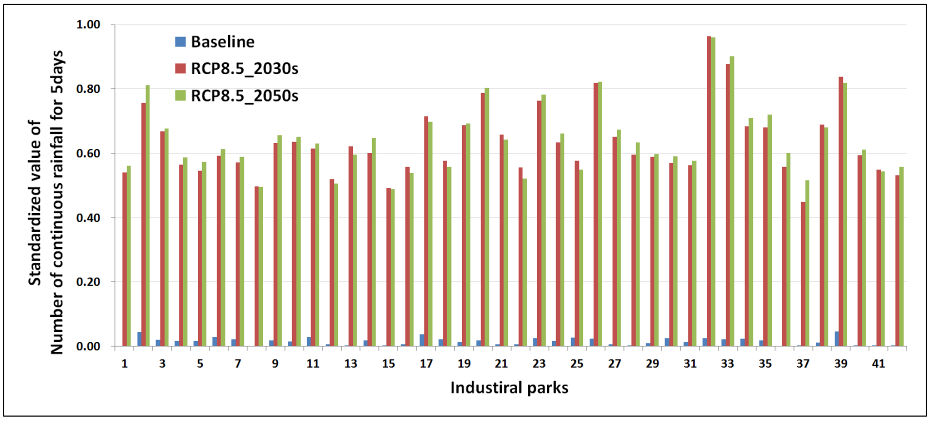


Figure 16. Standardized value of Number of Days for more than 5 Consecutive Days by Industrial Park according to Scenario of Climate Change (RCP8.5 Scenario)

Comparing the industrial parks where the enterprises subject to research are located, it was found that the frequency of five consecutive rainy days occurring would be increased in all four industrial parks, as shown below (Table 7). Particularly, considering all scenarios, OS was rated at the 4th grade level by 2050, showing high probability of such rainfall. Bae and Lee (2010) assessed the Ulsan area as having high flood probability now and in the future as the results of generating the climate exposure variable using the number of days with daily precipitation more than 80mm, the daily maximum precipitation, and the maximum discharge as indexes. In research by Han et al. (2012), the Ulsan area was assessed as an area with the highest probability of climate exposure. In Ulsan, the precipitation is at the national average level, but torrential rainfall occurs frequently, and during the summer, fog occurs frequently in the industrial park. Since rainfall intensity can be increased according to future climate change, comprehensive risk assessment is needed through vulnerable area analysis.

Table 7. Results of rating number of five consecutive days of rainfall in industrial parks where enterprises subject to assessment are located.

Industrial parks	Index Rating				
	Baseline	2030s		2050s	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
GJ(1)	1	3	4	3	3
GN(4)	1	3	4	3	3
AS(22)	1	3	4	3	3
OS(27)	1	4	4	4	4

To assess the hazard, the mean value of two indexes was standardized and divided into equal intervals. Currently, all 42 industrial parks are ranked as 1st grade, showing that the hazard was assessed to be very low. However, the hazard for all 42 industrial parks are assessed at grades higher than normal for the future (Figure 17), which means that, considering both the intensity and frequency of rainfall, the hazard possibility of flooding in the future is higher than at present.

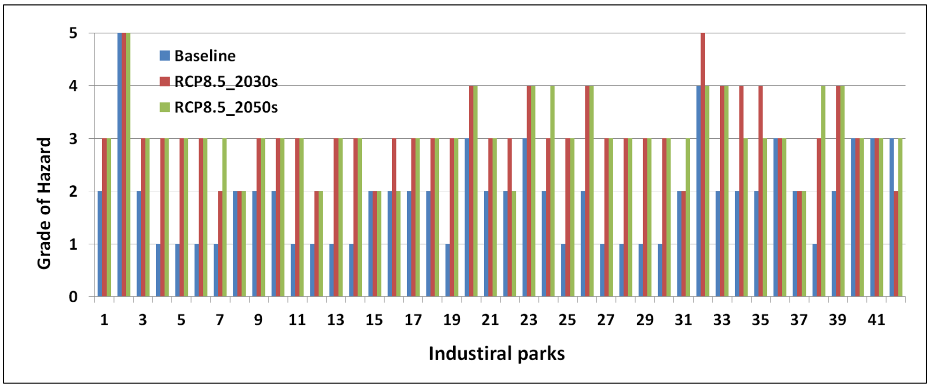


Figure 17. Changes in hazard rating by industrial park according to of climate change scenario RCP 8.5.

It was assessed that all the hazards in the industrial parks where the enterprises are subject to assessment are increased in the future compared to the present. The grades vary according to the regional characteristics, and GJ is currently ranked as 2nd grade, showing that the hazard grade is low. However, in climate scenario RCP 8.5, the hazard grade was increased by one step in the future (the 2030s and 2050s). It was observed that the hazard in GN and OS is increased by two steps according to the scenario of future climate change, because the intensity and frequency of rainfall in the relevant areas are increased in the future, Therefore, the vulnerability of the industrial parks and enterprises should be assessed comprehensively.

Table 8. Results of assessing hazard of industrial parks with enterprises subject to assessment.

Industrial parks	Grade of Hazard				
	Baseline	2030s		2050s	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
GJ(1)	2	2	3	3	3
GN(4)	1	2	3	3	3
AS(22)	2	2	3	3	2
OS(27)	1	3	3	3	3

2) Vulnerability result

As a results of standardizing the value of deduction the adaptation ability, the susceptibility are distributed from 0 to 1 point. Since it is the value that the standardization is performed, it can be classified into degrees with equal interval. In the vulnerability assessment results of the industrial parks where the enterprises subject to this assessment are located, AS, GJ and OS were assessed as 4th degree and GN was assessed as 2nd degree (Table 9). The industrial parks with high vulnerability are areas high probability of experiencing damage, considering the characteristics of the region, when flooding occurs.

Table 9. Grading of flood vulnerability assessment

Grade of Vulnerability	Number of industrial parks
5(0.8~1.0)	2,14,17,20,23,40,42
4(0.6~0.8)	GJ(1), AS(22), OS(27), 6,7,12,18,26,32,33,38
3(0.4~0.6)	3,9,13,15,21,28,30
2(0.2~0.4)	GN(4), 5,8,16,25,34,37,39,41
1(0~0.2)	10,11,19,24,29,31,35,36

In the vulnerability assessment results, GN, located in the Boryeong area, was assessed as 4th degree out of 5 degrees, which means that it is slightly vulnerable to flooding. Since GJ has a high average inclination and is good drainage, it has low susceptibility to flooding. Therefore, its susceptibility degree is 2nd degree, showing low susceptibility to flood compared with other national industrial parks. However, it does not have any backup facility in case there is a power supply problem due to flooding, a small green area, and no flood reduction facilities. Compared to other industrial parks based on this index, it was assessed as 1st degree because its adaptation ability is the lowest. In the vulnerability assessment results, since the difference between the susceptibility and the adaptation ability is relatively high, it was assessed as being slightly vulnerable (4th degree).

GN, located in the Gumi area, was assessed as 2nd degree, showing slight vulnerability to flooding. GN was built during the early industrial park development stage in the 1970s, and the vulnerability level, considering climate change and severe disasters at that time, was low. It is located close to the Nakdong River, and the altitude is low. However, since it has good drainage, the flood risk is not great. Therefore, when susceptibility is assessed based on the index, it is ranked as 2nd degree, showing low susceptibility. In addition, GN has various roads available even if flooding occurs, and is well equipped with infrastructure related to salvage. The production performance of the enterprises within the industrial park is higher than other areas, and the government provides good support against flood damage, even though Gumi City has created and manages the organization dedicated to infrastructure and disaster management. Since, accordingly, the adaptation ability is higher than the susceptibility, the flood vulnerability was represented as 2nd degree, showing a slightly safe level.

AS is located in Pyeongtaek, and the surrounding areas were assessed as 4th degree, slightly vulnerable to flooding. Asan is located in an area with soft ground on western coast, but the average altitude is high, and the number of available roads, flooding could affect logistics and the employees' commute. However, since the AS area has good drainage and few enterprises with high energy consumption, the susceptibility was assessed as normal (3rd degree). However, it does not have any reserve electric power facility for emergencies or enough flood reduction facilities, and only a small permeable area. It was thus assessed as 2nd degree, and in the aggregate vulnerability assessment, it was assessed as slightly vulnerable, since its adaptation ability is low, although the susceptibility is normal.

OS, located in the Ulsan area, was also assessed as an industrial park slightly vulnerable to floods. Since it has good drainage, although it was built in a low area on the coast line, the susceptibility was assessed as normal (3rd degree). However, its flood reduction facilities and the reserve power supply are not sufficient, nor its emergency facility to cope with injuries and property damage from flood, thus its adaptation ability was assessed as being slightly low (2nd degree).

3) Mesoscale risk matrix

The hazard and vulnerability assessed of the industrial parks where the three enterprises subject to mesoscale assessment are located are illustrated as a diagram in the risk matrix. The mesoscale risk was assessed by aggregating the hazards, climate exposure and vulnerability which means the area is vulnerable to flooding. Each hazard and vulnerability are illustrated as a diagram after classifying then into five degrees.

The mesoscale risk, for which each of them was aggregated, was classified as safe (green), normal (yellow), and dangerous (red).

Currently, GJ, which is located in the Boryeong area, has slightly high vulnerability to flooding, but the hazard was assessed as second degree, showing that the probability is low. In the future, the hazard would be increased by precipitation, but the aggregate risk was assessed as normal. GN, which is located in the Gumi area, has low vulnerability to flooding, and its current hazard was assessed as first degree, but in the future, it shows an inclination for increased hazard in some scenarios. When considering them comprehensively, both of them were assessed as safe or normal. AS, which is located in the area of Pyeongtaek, Gyeonggi-do, has high vulnerability to flooding, but the hazard was assessed below normal, and the aggregate risk was assessed as normal. OS, which is located in the Ulsan area, has high vulnerability to flooding, but its current hazard was assessed as very low and although it would be increased to normal, both of them were assessed as normal in the future.

The hazard was assessed between the 1st and 3rd degrees according to the characteristics of climate by area, and when considering the geographical characteristics or characteristics of the infrastructure, the vulnerability was assessed between the 2nd and 4th degrees. At the mesoscale, four industrial parks were assessed as having normal levels of risk but it the risk level is expected to be close to the dangerous level in the future, thus it is deemed that the individual risk would vary greatly depending on the degree of susceptibility and the adaptation ability of individual enterprises within the industrial park. Therefore, it is necessary to aggregate them by assessing the risk both at the mesoscale, which is assessed at the regional scale, and in the microscale, which is performed with individual enterprises.

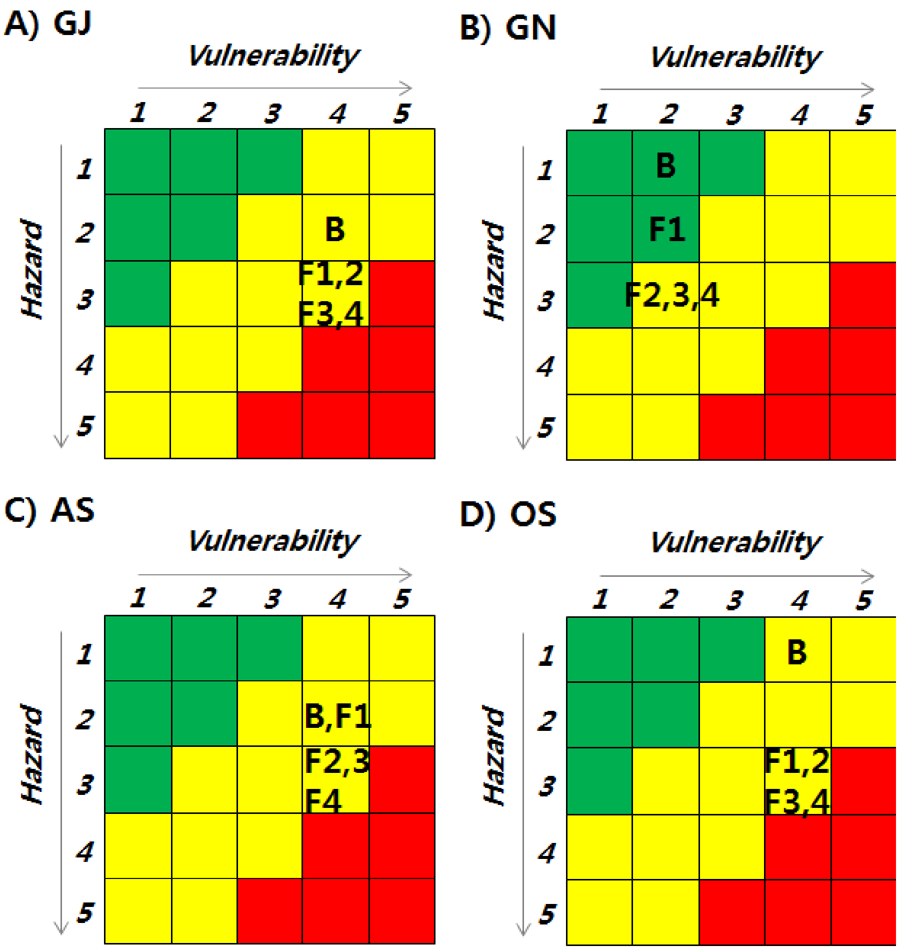


Figure 18. Risk matrix of vulnerability and hazard at each industrial park (A: GJ, B: GN, C: AS, D: OS). Green means safe, yellow means normal, red means dangerous. B and F indicate time series (B: baseline, F1: RCP 4.5 2030s, F2: RCP 4.5, 2050s, F3: RCP 8.5 2030s, F4: RCP 8.5, 2050s).

4.2. Microscale risk assessment

The flood risks were listed based on a review of both domestic and international literature, site surveys, and expert consultations. Then, the flood risks for the enterprises were drawn through in-depth interviews with officers of the enterprises subject to assessment. Considering profit-making, equipment, and materials, workers, compliance with processes, a total of three risks (flooding and destruction of production facilities, quality deterioration in raw materials and finished products, and production suspension by interruption of power generation due to destruction of power generation plant) were drawn.

Table 10. Microscale enterprise risk assessment items.

	Risk list
Risk 1	Flooding and Destruction of Production Facilities
Risk 2	Quality Deterioration in Raw Materials and Finished Products
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities

The probability and consequence of the three risks drawn from four enterprises (power plant, manufacturer of electronic components, EPS manufacturer, and pulp and paper manufacturer) were assessed. The probability and consequences were analyzed with five grades using the in–depth interviews with the enterprise officers, collected flood damage data (e.g., flooding area, recovery amount), and location of the enterprises subject to assessment. It was defined that the 5th grade has high flood probability and 1st grade has almost no probability. Since the business type and process stage, temperature, humidity, and locational characteristics vary by enterprise, the probability and the consequence were assessed by aggregating the characteristics of individual enterprises and cases of damage by flood. The assessment results were verified through more in–depth interviews with the enterprise officers. Finally, the risks were analyzed by aggregating them in a mesoscale risk matrix.

1) Probability of risks

The thermal power generation plant in Boryeong is located in GJ, and is composed of a steam power plant that uses bituminous coal as fuel and a combined–cycle power plant that uses LNG as fuel. A steam power plant generates electricity by converting steam obtained by heating water with bituminous coal into mechanical energy. The major facilities consist of boilers, steam turbines, and power plants, and the auxiliary facilities include condensation facilities, combustion facilities, water–supply facilities, fuel supply facilities, electrical installations, instrumentation and control facilities, and environmental facilities. A combined-cycle power plant first generates electricity using gas turbines, then generates power by operating steam turbines with the steam generated from the heat of exhaust gas.

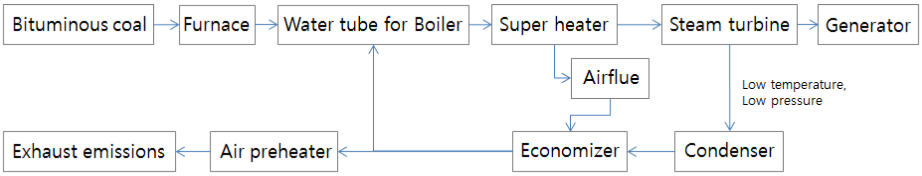


Figure 19. Power generation process of steam power plant

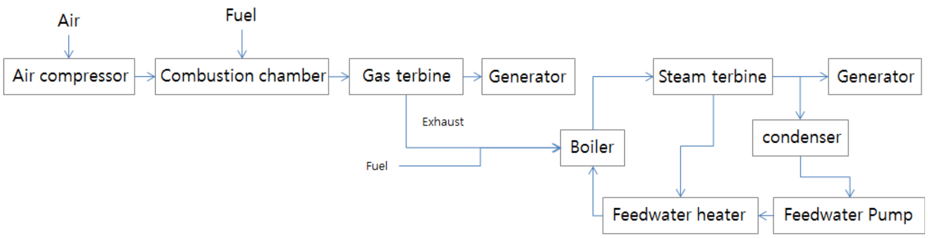


Figure 20. Power generation process of combined-cycle power plant

The damage was incurred in the power plant when torrential rainfall occurred during high tide, rather than a single event of torrential rainfall. The flooding damage was incurred by flooding of parts of the power plant by the torrential rainfall on August 15, 2012. The rain had fallen 68 mm/hour for three hours, the accumulated rainfall was 218 mm, and the damage was aggravated by overlapping with the high tide, which caused the slope to collapse, and the electric culvert for the 345 kV transmission line to be flooded. Some facilities in power plants 1, 2, and 3 were flooded (TBN sump pit, cable room, cond pit, 345 kV tunnel). Facilities located underground were also flooded. A cost of approximately 50 million won was incurred by three power plants, for additional sump pumps. Actually, the damage was caused by torrential rainfall, and since the probability of flood damage to installations and facilities located in lowlands is high, Risk 1 was assessed as 4th grade, with slightly high probability. Efficiency can be deteriorated during flooding if bituminous coal is used, because bituminous coal is stored outdoors, but the damage has not been well recorded. In addition, since the final product of the power plant is electricity, the efficiency of such fuel does not affect the quality of the product. However, if the power supply is interrupted by torrential rainfall, strong wind, or lightning during transmission through towers and power cables, great damage is incurred in the power plant. Since torrential rainfall occurs intermittently, the risk was assessed as 2nd grade, which is slightly probable.

Table 11. Flood risk probability assessment at power plant.

	Risk list	Grade of Probability
Risk 1	Flooding and Destruction of Production Facilities	4
Risk 2	Quality Deterioration in Raw Materials and Finished Products	2
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities	1

The manufacturer of electronic components located in GN, in the Gumi area, produces camera modules and packaging substrate, which are the components of electronic devices. The production process requires maintaining the temperature to 22 ± 2° C and the humidity to 50 ± 5% during production. To maintain such temperature and humidity, production takes place in a clean room. If it rains continuously, the number and operating rate of the equipment to control humidity in the clean room can be varied. Therefore, flooding can cause changes in the power consumption to maintain conditions in the clean room, rather than having a direct impact on the individual processes of manufacturing electronic components.

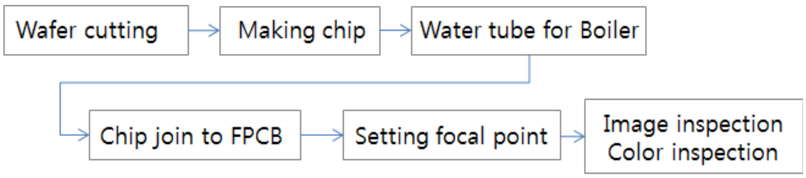


Figure 21. Camera module manufacturing process

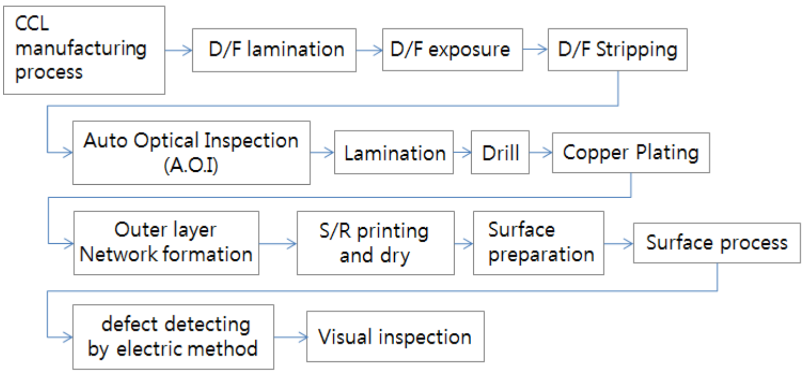


Figure 22. Package substrate manufacturing process

Since the raw materials needed by the manufacturer of electronic components and the finished products are stored indoors, flooding due to torrential rains will not have a direct impact on production. Therefore, Risk 2 was assessed as 1st grade (the lowest probability). However, since the manufacturing process uses ultra–pure water, defect can result if the water treatment facility is defective. In addition, since the electricity consumption is high (70% of the energy used by the subject enterprises), if the power supply is interrupted by flooding, production may be suspended. Indeed, some production lines have been suspended 3-4 times a year because of changes in the power supply (sag/instantaneous voltage sag) or phenomena such as typhoons, floods, and lightning. Therefore, Risk 3 was assessed as 4th grade, (high probability). In GN, the manufacturer of electric components is located near the Nakdong–River, thus the probability of the production facility being flooded or destroyed is high. Actually, the adjacent enterprises and road were flooded for approximately five hours by Typhoon Sanba in September 2012. Although direct damage has not been incurred in the past by the enterprises subject to assessment, Risk 1 was assessed as 3rd grade, judging that there is probability of flooding.

Table 12. Flood risk probability assessment for manufacturer of electric components.

	Risk list	Grade of Probability
Risk 1	Flooding and Destruction of Production Facilities	1
Risk 2	Quality Deterioration in Raw Materials and Finished Products	3
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities	4

EPS manufacturer located in AS in the Pyeongtaek area produces buffer material (EPS, EPP), insulation materials (EPS), and sound insulation materials (EPS). In the production process, the products are passes through phases such as action, sand figuration. Pustulation expands the raw material after softening it with water, air, and, steam. The heat medium is saturated steam, and has advantage of establishing the proper temperature range by changing the pressure. Maturation refers to the internal pressure gradually becoming equal to atmospheric pressure as the air penetrates the foam particles when the internal pressure is reduced, as the foaming materials are rejected after pustulation, and makes the residual foam material endure external pressure by maturing and volatilizing it. Figure 22 23, and 24 are the process of making the product by placing the EPS in molds after maturing and drying the foamed EPS for a certain period and by applying steam.

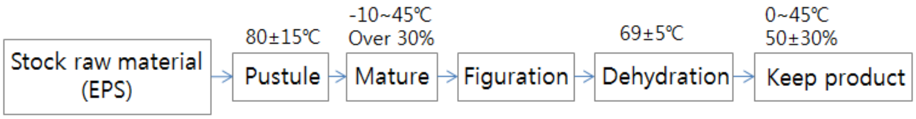


Figure 23. EPS buffer material manufacturing process

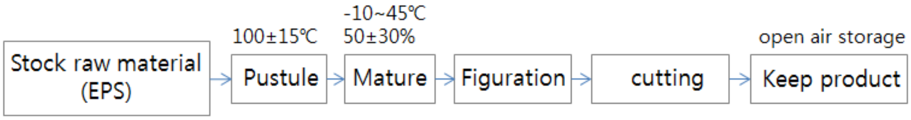


Figure 24. EPS insulation material manufacturing process

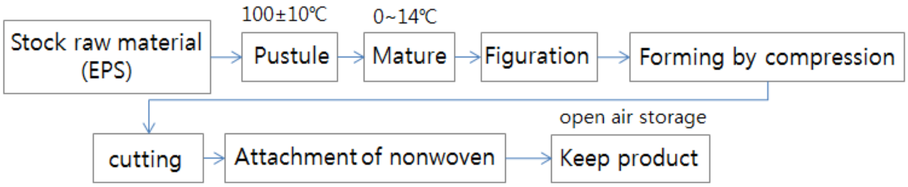


Figure 25. EPS Sound insulation materials manufacturing process

Above <Figure 23, 24 and 25> show the process of manufacturing EPS buffer materials, EPS insulation materials, and EPS sound insulation materials in the enterprise subject to assessment. Since in the pustulation, maturation, and figuration processes, high temperatures and proper humidity need to be maintained, they may be susceptible to changes in temperature and humidity. Particularly, during pustulation, high temperature must be maintained, and in maturation, humidity (30-50%) must be maintained at room temperature. When flooding occurs because of torrential rainfall, humidity could increase and the temperature could drop, and as the temperature should be maintained above a certain temperature to reduce the defect ratio of the product, precautions should be taken.

Out of all the processing stages, the raw material import, figuration, and storage stages can be affected by flooding. Particularly, since the finished products are mostly stored outdoors, except for the EPP and EPS buffer materials, they can be swept away by torrential rainfalls that are accompanied by strong winds. There has been a case where some finished products were swept away by strong wind. Therefore, Risk 2, which is the quality deterioration of raw material and finished product (R2), was assessed as 3rd grade. Since all the related transportation, from raw material supply to product sales in the enterprise, are limited to domestic transport, the flood risk during transportation was small. Since the subject enterprise is not located on the coastline and the drainage system is managed well, flooding and destruction of the production facilities do not occur, and the flood risk of the production facility was assessed as 1st grade (the least probability). In addition, in the area where the EPS manufacturer is located, no power supply interruption has occurred by destruction of electrical facilities and the seasonal variation in power consumption is low. Therefore, it was judged that it would not be susceptible to the season when flooding occurs frequently, and Risk 3 was assessed as 1st grade (the least probability).

Table 13. The grade of flood risk probability assessment for EPS Manufacturer

	Risk list	Grade of Probability
Risk 1	Flooding and Destruction of Production Facilities	1
Risk 2	Quality Deterioration in Raw Materials and Finished Products	3
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities	1

The processes of the pulp and paper manufacturer located in OS, Ulsan, is divided into the pulp process, which commercializes pulp by producing it from wood chips, and the paper-making process, which makes the paper by transferring pulp to the sheet-making process prior to commercializing pulp. To produce pulp and paper, the enterprise subject to assessment uses domestic pine trees and some imported woods to form chips, and keeps them in an open-air storage yard. It then transfers them to the digester and bleaches them, after separating the lignin and cellulose from the chips and cleaning them, consuming large amounts of water in this process. The water temperature is 80-90° C, and the amount of water consumed is 65,000 tons per day. Paper is produced by coating and cutting, through compression and dehydration stages after bleaching. The facilities consist of, among other things, boilers, transformers, air compressors, and freezers, and has power processes-using black liquor generated in the paper-making and pulp processes.

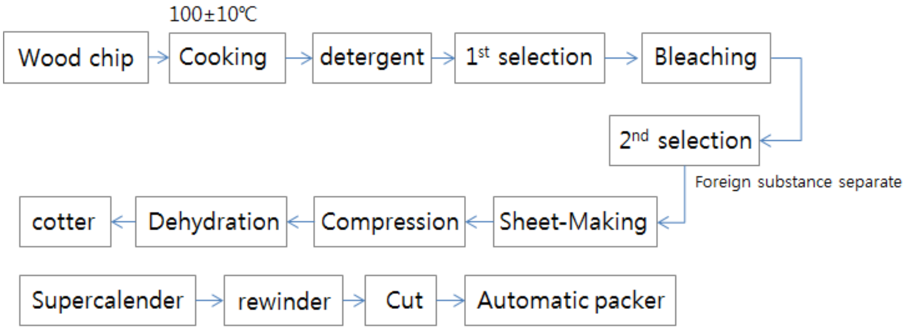


Figure 26. Integrated pulp and paper processing

Pulp and paper are mostly made using domestic pine trees from thinning as raw material, although sometimes, imported wood chips are used. When wood chips are imported as raw material, they are received once every two or three weeks to prepare for torrential rainfall accompanied by strong winds, and when the weather deteriorates, the raw material supply ship departs several days later. Large amounts of raw materials are supplied once every one or two weeks and stored in open-air storage yards, and production can proceed for one week without new supply of raw material. However, the wood chips, which are the raw material, and the paper and pulp, which are the finished product, are stored in open-air storage yards, thus the quality of the raw material and the finished products can be deteriorated when flooding occurs. However, since the subject enterprise is located on higher ground in OS, it has not experienced any damage, although damage was incurred in adjacent enterprises during the torrential rainfall in 2009. Therefore, the production facility flooding and destruction risk (Risk 1) was assessed as 2nd grade, which corresponds to almost no probability. However, since the location of the open-air storage yard is relatively low within the same enterprise, rainwater can gather there, and the probability of flood risk (Risk 2) was assessed as 4th grade, which is corresponds to slightly high. Since no great damage has been incurred by large typhoons, the risk of power generation facility destruction by flooding (Risk 3) was assessed as low (1st grade).

It was found that more damage is incurred in the subject enterprise from the deterioration of wastewater treatment and the increase of the defect ratio due to increased humidity in the process than flooding of facilities during torrential rainfall. The capacity of the wastewater treatment facility is approximately 78,000 ㎥, and the normal operation capacity is 60,000 ㎥. However, since the operation capacity during torrential rainfall is 70,000 ㎥, approximately 300 million won of damage is incurred every year by the increased facility maintenance cost because rainwater that flows into the wastewater treatment facility increases the amount of wastewater to be treated. In addition, since the defect ratio and the basic unit of process energy are increased when the humidity is increased during production processes, 30 million won of annual damage is incurred when flooding occurs.

Table 14. The grade of flood risk probability assessment for pulp and paper manufacturer

	Risk list	Grade of Probability
Risk 1	Flooding and Destruction of Production Facilities	2
Risk 2	Quality Deterioration in Raw Materials and Finished Products	4
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities	1

Three risks (Risk 1, Risk 2, Risk 3) of damage that can be incurred in the enterprise because of flooding were determined, and their probabilities were assessed using in-depth interviews with the enterprise officers and the damage data. In the assessment results, four enterprises showed different probabilities for the same risk. These results were caused by diverse factors such as the facilities and installations of the enterprises, differences in production processes according to business type, and characteristics of raw materials. The risks analysis results were again verified through in-depth interview with the enterprise officers, and the assessment results were used to prepare the microscale risk matrix.

2) Consequence of risks

The assessment results of the consequence of flood risk were compiled depending on the characteristics of the enterprise and the business type. The consequence of the risk in the thermal power plant located in GJ was classified as 4th grade, showing that considerably great damage may occur, because flooding occurs when torrential rainstorms coincide with high tide, causing greater damage, in terms of area and recovery cost, than damage from any other climate exposure. Analysis showed that, since the power plant subject to assessment uses some of the electricity it generates, almost no damage was incurred to the power plant, although power generation was interrupted.

Table 15. The grade of consequences of flood risk at power plant

	Risk list	Grade of Consequency
Risk 1	Flooding and Destruction of Production Facilities	4
Risk 2	Quality Deterioration in Raw Materials and Finished Products	4
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities	0

Since EPS manufacturer in GN operates in an air-conditioned environment, it is not much impacted by temperature and humidity, but it was assessed that the power consumption needed for temperature and humidity control can increase. Therefore, the consequence of Risks 1 and 2 (physical damage by flooding) was assessed to be low. It was assessed that when the power supply is interrupted, production is not greatly affected.

Table 16. The grade of consequences of flood risk for manufacturer of electronic components

	Risk list	Grade of Consequency
Risk 1	Flooding and Destruction of Production Facilities	2
Risk 2	Quality Deterioration in Raw Materials and Finished Products	2
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities	2

In the EPS manufacturer in AN, the semi-finished products stored outdoors can be swept away or damaged by torrential rainstorms accompanied by strong winds because they are not heavy. Therefore, it was assessed that when flooding occurs, the consequences of Risks 1, 2, and 3 are considerable.

Table 17. The grade of Consequences of flood risk for EPS manufacturer

	Risk list	Grade of Consequency
Risk 1	Flooding and Destruction of Production Facilities	3
Risk 2	Quality Deterioration in Raw Materials and Finished Products	4

	Risk list	Grade of Consequency
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities	4

The pulp and paper manufacturer located in OS, in Ulsan, is located on high ground. Since it does not have any underground facilities, the consequence of Risk 1 was assessed as 1st grade. For Risk 2, the probability of flood risk is small but the raw materials and products are susceptible to moisture. Therefore, the consequence of Risk 2 was assessed as 3rd grade, which is the normal level. When the power supply is interrupted (Risk 3), there exists an emergency power generation facility, thus when the power supply is interrupted, the impact was assessed as normal.

Table 18. The grade of consequences of flood risk for a pulp and paper manufacturer

	Risk list	Grade of Consequency
Risk 1	Flooding and Destruction of Production Facilities	1
Risk 2	Quality Deterioration in Raw Materials and Finished Products	3
Risk 3	Production Suspension by Interruption of Power Generation due to Destruction of Power Generation Facilities	3

3) Microscale risk matrix

Three risks, which can be applied commonly to four subject enterprises, were drawn (Risk 1, Risk 2, and Risk 3), and their probabilities and consequences were assessed using five grades. The assessment results were classified as safe (green), normal (yellow), and dangerous (red). When illustrating four enterprises in the risk matrix comprehensively, cases where the consequence is great and the probability is low are assessed as normal, and cases where the consequence is small and risk occurs frequently by flooding are assessed as normal.

Since some parts of the power plants are located in low altitude areas, it was assessed that the production facilities' flooding and destruction risk would be great. The quality deterioration of raw material and products by flooding was assessed as normal (R2), and the production suspension risk (R3) was assessed to have small probability and consequence. Therefore, to reduce the Risk 1 level, which was assessed as dangerous, it is necessary to install additional drain pumps and to prevent rainwater inflow to the facilities and underground installations located at low altitudes. Actually, the power plant within GJ has installed submerged pumps and engine pumps, and prevented rainwater inflow to the area that was partly flooded after damage from torrential rainfall. A cost of approximately 50 million won was incurred in three power plants to buy additional sump pumps as adaptation measures to reduce risk, considering future climate change in the long-term.

The risk of flooding and destruction of production facilities in the EPS manufacturer (Risk 1) was assessed as safe because its probability is very low, while the consequence is normal. Although the risk of quality deterioration of raw materials and finished products (Risk 2) was normal, since the consequence is slightly large, it was assessed as normal. The suspension of production by the power supply interruption due to destruction of power generation facilities (Risk 3) was assessed as dangerous because the probability is high and the consequence is considerable.

The risk of flooding and destruction of production facilities in the manufacturer of electric components (Risk 1) was assessed as safe because its probability is low and the consequence is small. Although the quality deterioration of raw materials and finished products (Risk 2) and suspension of production by power supply interruption due to destruction of power generation facilities (Risk 3) have normal or slightly high probabilities, since their consequence is small, they were assessed as normal.

The risk of flooding and destruction of production facilities in the pulp and paper manufacturer (Risk 1) was assessed as safe because its probability is low and the consequence is trivial. Although the risk of quality deterioration of raw materials and finished products (Risk 2) is normal, since the probability is high, it was assessed as dangerous. The suspension of production by power supply interruption due to destruction of power generation facilities (Risk 3) was assessed as safe because the probability is very low, while the consequence is normal.

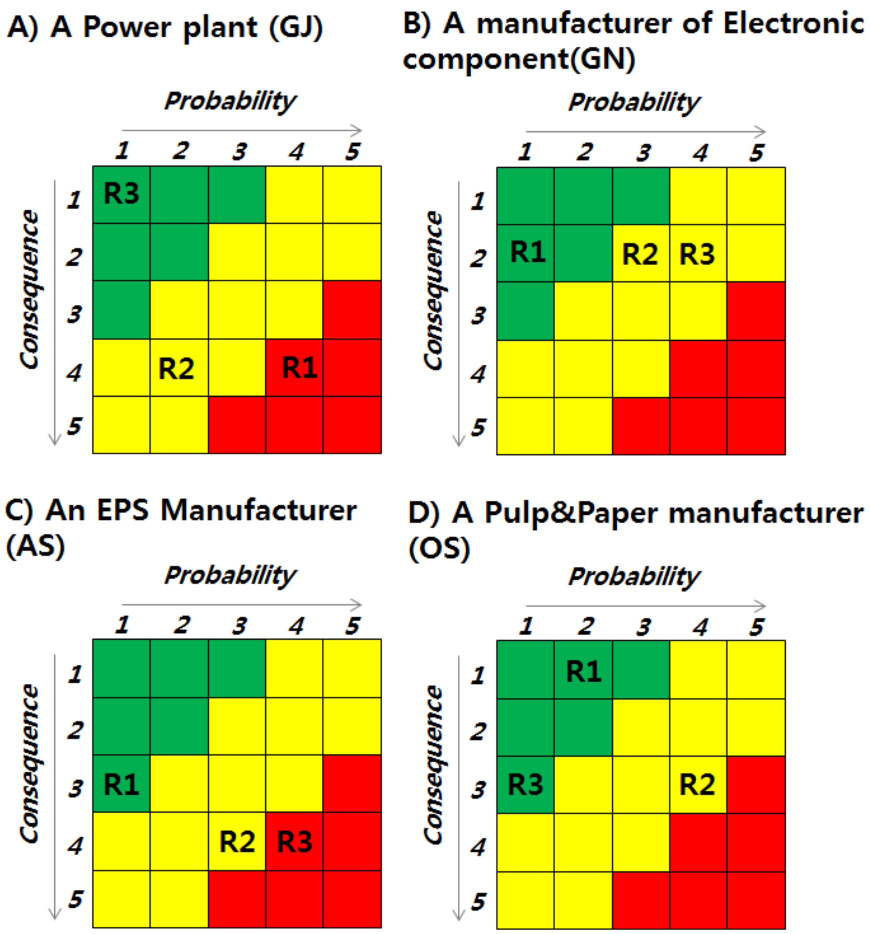


Figure 27. Microscale enterprise risk assessment results. Risk matrix is classified as dangerous (red), normal (yellow), and safe (green).

4.3. Total risk assessment

The mesoscale flood risk was assessed considering the climate factor, and geographical characteristics and infrastructure in the industrial parks where the enterprises are located. The hazard was assessed with the climate factor as the index related to flood, and the vulnerability, which is the results of assessing areas vulnerable to flood, and was shown with a risk matrix by classifying it into five grades. In the microscale, to assess the flood risk, the potential risks in the enterprise were determined, and the probability and consequence against the relevant risk were assessed. The comprehensive risk level by risk (Risk 1, Risk 2, and Risk 3) was assessed by aggregating the results of the risk assessment in two spatial units using the risk matrix. In the mesoscale, although the climate change both in the present and future were considered, since it is difficult to analyze the enterprise's plan to respond to future climate change quantitatively, the analysis was made based only on the present. Therefore, although there is no consideration for the future, the microscale risk can be changed if the enterprise were to invest or take proper actions to resolve the risks.

1) Gojung National Industrial Park : A power plant

When aggregating the assessment results by the flood risks

(Risk 1, 2 and 3) that can occur in the power plant at the mesoscale and microscale, Risk 1, Risk 2, and Risk 3 were assessed as dangerous, normal, and safe, respectively (Figure 28). In the microscale, Risk 1, Risk 2, and Risk 3 were assessed as dangerous, normal, and safe, respectively. At the mesoscale, the flood risk was assessed as 2nd grade both for the present and future (2030s and 2050s), indicating medium risk (Table 19).

Table 19. Flood risk assessment results in manufacturer of power plants. Each value is a represented grade of risk assessment results in the two spatial scales. This risk assessment was to target the baseline, 2030s and 2050s. For the future, the RCP 8.5 and RCP4.5 scenarios were used. The flood risk assessment on Mircoscale was evaluated for three risk items.

<table>
<tr><th colspan="3">Mesoscale</th><th colspan="2">Mircoscale</th></tr>
<tr><td colspan="2">Baseline</td><td>2</td><td rowspan="2">Risk 1</td><td rowspan="2">3</td></tr>
<tr><td rowspan="2">2030s</td><td>RCP 4.5</td><td>2</td></tr>
<tr><td>RCP 8.5</td><td>2</td><td rowspan="2">Risk 2</td><td rowspan="2">2</td></tr>
<tr><td rowspan="2">2050s</td><td>RCP 4.5</td><td>2</td></tr>
<tr><td>RCP 8.5</td><td>2</td><td>Risk 3</td><td>1</td></tr>
</table>

The flood assessment results in two spatial scales by risk (Risk 1, 2, and 3) are shown in Figure 24. Since there was no change in the grade, although the future was considered, one comprehensive risk assessment result value by each risk was drawn.

When aggregating the risk assessment results for Risk 1 at the mesoscale and microscale, it was classified as dangerous, because although the flood risk is normal in the industrial park, the enterprise risk is great. Since Risk 2 both at the mesoscale and microscale is normal, it was classified as normal. Since Risk 3 is very low at the microscale and small at the mesoscale, it was assessed as safe.

Therefore, in case of power plants, investment and maintenance of the facilities and installation are needed against flooding. Since the mesoscale risk is not increased by future climate change, it is necessary to determine the preparation level based on past flooding damage.

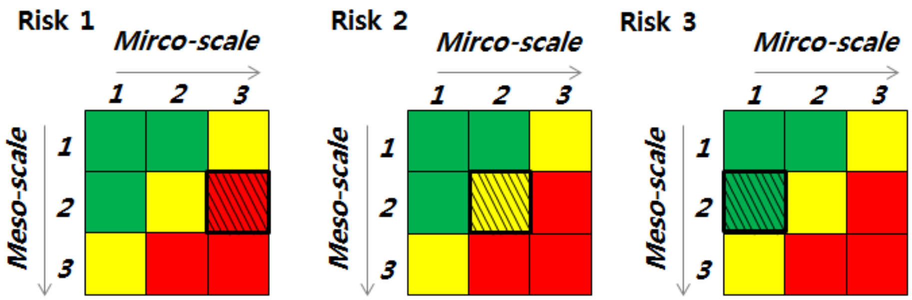


Figure 28. Comprehensive flood risk assessment result for a power plant. Results of rating risks from present to future (2030s and 2050s) by microscale and mesoscale risk. The black hatched areas indicate the level of each risk in the present and future (safe: green, normal: yellow, dangerous: red).

2) Gumi National Industrial Park : A manufacturer of Electronic components

The assessment results by flood risks (Risk 1, 2, and 3) that can occur in the manufacturer of electronic components at the mesoscale and microscale were aggregated. (Figure 29). At the microscale, Risk 1, Risk 2, and Risk 3 were assessed as safe, normal, and normal, respectively. At the mesoscale, the flood risk was assessed as safe (1st grade) for the present and as normal (2nd grade) for the future (the 2030s and 2050s).

Table 20. Flood risk assessment results for manufacturer of electronic components. Each value is a represented grade of risk assessment results in the two spatial scales. This risk assessment was to target the baseline, 2030s and 2050s. For the future, the RCP 8.5 and RCP4.5 scenarios were used. The flood risk assessment on Mircoscale was evaluated for three risk items.

Mesoscale			Mircoscale	
Baseline		1	Risk 1	1
2030s	RCP 4.5	1	Risk 2	2
	RCP 8.5	2		
2050s	RCP 4.5	2	Risk 3	2
	RCP 8.5	2		

The flood assessment results in two spatial scales by risk (Risk 1, 2, and 3) are shown in Figure 28. There was a change in the grade when the future was considered, thus one comprehensive risk assessment result value for each risk was drawn.

When aggregating the risk assessment results for Risk 1 in the mesoscale and microscale, it was classified as dangerous level, which is because although the flood risk is normal in the aspect of industrial park, the enterprise risk is great. Since the Risk 2 both in the mesoscale and microscale is the normal level risk, it was classified as normal level. Since Risk 3 is very low in the microscale and is small in the mesoscale, it was analyzed as safe level. In the mesoscale, no change was found in the flood risk assessment results. Therefore, it is necessary to establish the management and investment plan considering the range of fluctuation for the present and the future comprehensively.

Considering climate change when aggregating Risk 1 assessment results in both the mesoscale and microscale, it was classified as safe (1st grade), because although the flood risk is safe and normal in the industrial park, the enterprise risk is low. Since Risk 2 both at the mesoscale and microscale is normal, it was classified as normal. Since Risk 3 is very low at the microscale and small at the mesoscale, it was assessed as safe.

Therefore, in case of power plants, investment in and maintenance of the facilities and the installation are needed against flooding and destruction of the production facilities by flooding. Since Risk 2 at the mesoscale is a low or normal, when aggregating them, it was classified as safe and normal, even when climate change is considered. Although in the microscale, there is normal risk for Risk 3, at the mesoscale, there was a change from low to normal based on climate change. Therefore, the comprehensive risk for Risk 3 should be considered both safe and normal.

Therefore, in case of manufacturers of electronic component, since the risk can increase from safe to normal, although it does not have dangerous risk, long-term management of the quality of raw materials and products and the power supply should be performed.

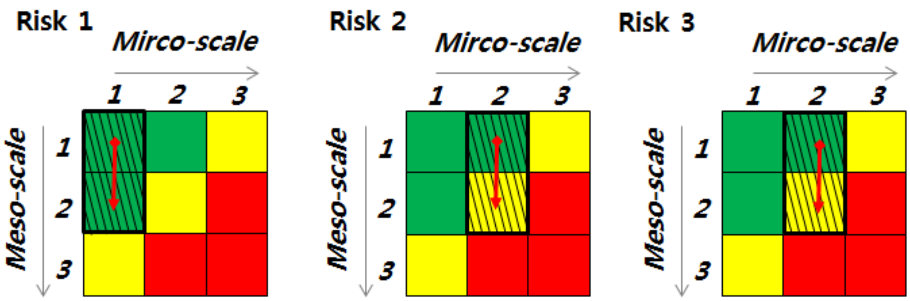


Figure 29. Comprehensive flood risk assessment result for a manufacturer of electronic component. Results of rating risks from present to future (2030s and 2050s) by microscale and mesoscale risk. Black hatched areas indicate fluctuation in the level of each risk in the present and future (safe: green, normal: yellow, dangerous: red).

3) Asan National Industrial Park : An EPS manufacturer

When aggregating the risk assessment results by flood risks (Risk 1, 2 and 3) that can occur in the EPS manufacturer, at the mesoscale and microscale, Risk 1, Risk 2, and Risk 3 both in the present and future were classified as safe, safe and normal, and dangerous, respectively. In the microscale, Risk 1, Risk 2, and Risk 3 were assessed as safe, normal, and dangerous, respectively. At the mesoscale, the flood risk was at the normal level (2nd grade) for both the present and future (Table 21).

Table 21. Flood risk assessment results for EPS manufacturer. Each value is a represented grade of risk assessment results in the two spatial scales. This risk assessment was to target the baseline, 2030s and 2050s. For the future, the RCP 8.5 and RCP4.5 scenarios were used. The flood risk assessment on Mircoscale was evaluated for three risk items.

<table>
<tr><th colspan="3">Mesoscale</th><th colspan="2">Mircoscale</th></tr>
<tr><td colspan="2">Baseline</td><td>2</td><td rowspan="2">Risk 1</td><td rowspan="2">1</td></tr>
<tr><td rowspan="2">2030s</td><td>RCP 4.5</td><td>2</td></tr>
<tr><td>RCP 8.5</td><td>2</td><td>Risk 2</td><td>2</td></tr>
<tr><td rowspan="2">2050s</td><td>RCP 4.5</td><td>2</td><td rowspan="2">Risk 3</td><td rowspan="2">3</td></tr>
<tr><td>RCP 8.5</td><td>2</td></tr>
</table>

The flood assessment results in two spatial scales by risk (Risk 1, 2, and 3) are shown in Figure 30. There was a change in the grade at the mesoscale when the future was considered.

When aggregating the risk assessment results for Risk 1 at the mesoscale and microscale, it was classified as dangerous even when considering climate change, is because although the flood risk is safe and normal in the industrial park, the enterprise risk is low. Since Risk 2 both at the mesoscale and microscale is normal, it was classified as normal. Since Risk 3 is normal at the mesoscale but great in the microscale, it was analyzed as dangerous when assessing them comprehensively. Therefore, it is necessary for the enterprise to prepare against the risk of power supply interruption. In the EPS manufacturer, the flood probability is low, considering the geographical and climatic factors, and that the infrastructure is well managed. However, since the processes that are susceptible to temperature and humidity can be affected by instantaneous power failure during torrential rainfall, flooding, or rainfall accompanied by strong wind, it was assessed that management of the power supply and back-up facilities is needed.

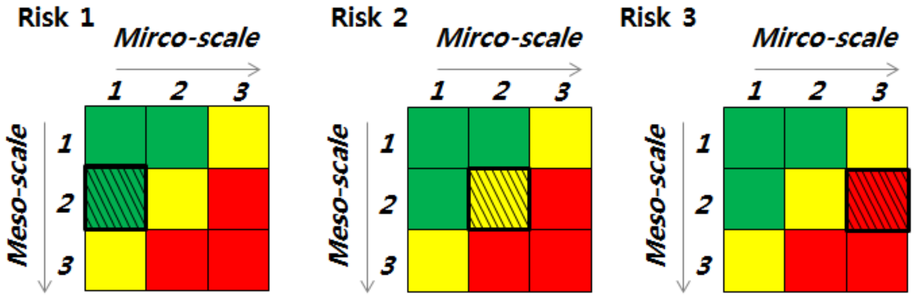


Figure 30. Comprehensive flood risk assessment result in EPS manufacturer results of rating risks from present to future (2030s and 2050s) by microscale and mesoscale risks. Black hatched areas indicate level of each risk in the present and future (safe: green, normal: yellow, dangerous: red).

4) Onsan National Industrial Park : A pulp and paper manufacturer

When aggregating the risk assessment results by flood risks (Risk 1, 2 and 3) that can occur in the pulp and paper manufacturer, at the mesoscale and microscale, Risk 1, Risk 2, and Risk 3 were classified as safe, normal, and safe, respectively (Figure 31). At the microscale, Risk 1, Risk 2, and Risk 3 were assessed as safe, normal, and safe, respectively. At the mesoscale, the flood risk was at the normal level (2nd grade) for both the present and future (Table 22).

Table 22. Flood risk assessment results for pulp and paper manufacturer. Each value is a represented grade of risk assessment results in the two spatial scales. This risk assessment was to target the baseline, 2030s and 2050s. For the future, the RCP 8.5 and RCP4.5 scenarios were used. The flood risk assessment on Microscale was evaluated for three risk items.

Mesoscale			Microscale	
Baseline		2	Risk 1	1
2030s	RCP 4.5	2		
	RCP 8.5	2	Risk 2	2
2050s	RCP 4.5	2		
	RCP 8.5	2	Risk 3	1

The flood assessment results in two spatial scales by risk (Risk 1, 2, and 3) are shown in Figure 27. Since at the mesoscale, the flood risk is not affected by climate change, the risks for the present and future (2030s and 2050s) were assessed as being same, because although the flood risk is safe and normal in the industrial park, the enterprise risk is low. Since Risk 2 both at the mesoscale and microscale is normal, when the two scale were aggregating, the risk was classified as normal, even when climate change is considered. Since Risk 3 is low at the microscale and is normal, there was a change. Therefore, in the case of pulp and paper manufacturers, there is no dangerous risk, and for Risk 2, it was assessed that caution is needed because of the characteristics of the business, which requires wood as raw material. To reduce the flood risk in the enterprise, it needs to pay attention to the humidity of raw materials and finished products, as well as flood damage.

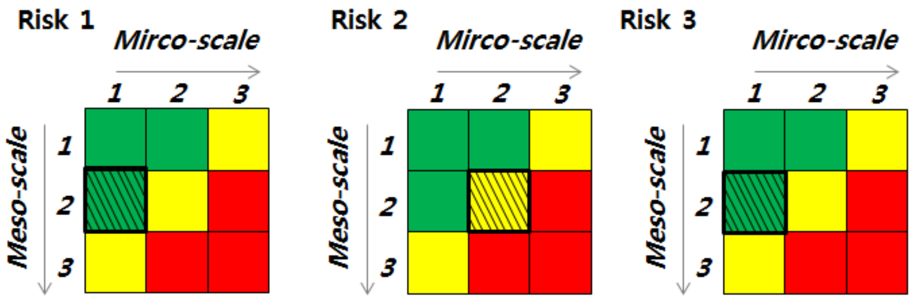


Figure 31. Comprehensive flood risk assessment result in pulp and paper manufacturer from rating risks from present to future (2030s and 2050s) by microscale and mesoscale risks. Black hatched areas indicate the level of each risk in the present and future (safe: green, normal: yellow, dangerous: red).

5. Discussion

In this study, in order for a business to preemptively respond to future flood damage due to climate change, a multiscale flood risk assessment method was suggested. The circumstances, characteristics, and geography of the business and regional infrastructure were all taken into consideration, and different methodologies were applied according to this purpose.

This study involved two hypothesis: first, there is a difference between the urban and industrial sectors regarding when flooding induced by torrential rainfall may occur; second, the flood risks in business will be different depending on the characteristics of the company and surrounding region. To solve the first hypothesis, actual flood damage cases in industrial parks and businesses were collected and analyzed in relation to the rainfall event. As a result, although previous studies used the number of rain days with more than 80 mm rainfall as an indicator of torrential rainfall, a trend was shown whereby flooding damage occurred in the industrial sector when a rainfall event over 100 mm occurred. To solve the second hypothesis, a multiscale risk assessment method was developed by separating the mesoscale and microscale risk through a literature review and in-depth interviews, and subsequently aggregating the two scales of risk.

There have been diverse attempts made to consider climate change related to the industrial sector but the situation for businesses has not been considered due to difficulties in data collection, etc. This study, therefore, developed an assessment method that was specific to individual businesses, flood damage cases, in-depth interview data, etc. Currently, domestic studies related to climate change-related flood risk assessments for companies are in the initial stage of determining risk by business type. Internationally, studies assessing the risks for the characteristics of the business type have been performed, rather than assessing individual company risks. Most of these studies determined the flood risk by business type and performed questionnaire surveys on various businesses after selecting certain risks. They assessed the risk by analyzing the investigation results, as well as previous damage cases. Therefore, this study is valuable in that the flood risk assessment method comprehensively considers the company and degree of climate change according to the relevant geographical characteristics.

In this study, a flood risk assessment method developed from four businesses was applied. It used current and future (2030s and 2050s) years as target years and climate change was considered on the mesoscale. However, on the mesoscale, since a business in not likely to change or perform maintenance of facilities due to climate change in the near future, only the present was considered. This is a limitatioin of the research with regards to the in-depth interview, and the damage to business facilities can be determined based on examples from the in-depth interviewee. Therefore, in the microscale, this study only considered the present.

After applying the developed model to four businesses, the mesoscale flood risk in the Gumi area was assessed as a safe level for both current years and the 2030s under RCP scenario 4.5. Areas where three of the businesses were located were assessed as a normal level. On the microscale, the no. 1 item on the power plant risk list and the no. 3 item on the EPS manufacturer risk list were assessed as being at normal and safe levels, respectively, and other company risk items were also assessed as being at normal and safe levels. The final business risks were assessed by aggregating the flood risk assessment results at the mesoscale and microscale.

For the power plant, the production facility flood and damage risks were assessed as being at dangerous levels. The impact of the flood on the raw material was assessed as a normal level and the impact of flooding on power transmission was assessed as a safe level. Power plants are part of the national infrastructure and the particular business subject to assessment is the largest domestic power generation company. Therefore, when the location was selected, its durability against flood, typhoon, etc. was of particular importance considering the threat of natural disasters. However, when the facilities were initially built, climate change was not considered; therefore, when rainfall events exceed the predicted rainfall frequency at the time of design, the risks can be significantly increased. The results show that, when considering the location and conditions of this type of infrastructure, even in the future (2030s and 2050s), it was assessed as a normal risk level. However, if such a flood did occur, the damage would affect the company by flooding the facility or raw materials stored in open-air yards. In fact, when a rainfall event of 80 mm/hour lasts more than 6 hours, the flooding damage would include the low lying areas within the business and additional costs incurred to recover and prepare the flood damage to facilities due to unexpected local torrential rainfall. Therefore, it is necessary to check if there is any possibility of general flooding of the facilities, and in the case of facilities on low lying land, to check the drainage conditions.

At the mesoscale, the flood risk assessment results for the electronic manufacturer located in the Gumi area were at safe levels both in the present and near future, but further in the future, it changed to normal levels. Since the Gumi area experienced flood damage early in the 2000s, the infrastructure has been serviced accordingly by establishing countermeasures to reduce the damage from storms and floods at the government level, and by the installation of flood prevention facilities. Although Nakdong River runs through the center of a national industrial park, thorough flood preparations have been made regarding the location and infrastructure; therefore, the flood risk is small. Regarding the business, since the company subject to assessment manufactures electronic components, all production processes are performed under an air-conditioning system where the temperature and humidity are constantly controlled. Therefore, since the raw materials and the products are not stored in open-air yards, the no. 1 risk item was assessed as being at a safe level. Although all the products are stored indoors, they may still be affected by the humidity, therefore the no. 2 risk item was assessed as being at a normal level. Since the production process is highly dependent on electricity, sudden power interruptions due to torrential rainfall also cause damage to the business. However, because of the low probability and impact, the no. 3 risk item was also assessed as being at a normal level. When aggregating the risks, there was a slight change in the comprehensive flood risk assessment results. At the microscale, since the present and future conditions were the same, there were no changes in the rating after aggregation. The risk of deterioration of the raw materials and finished product quality, as well as the risk of sudden power interruption, changed from a safe level under current conditions to a normal level in the future, which means that the risk will increase in the future.

The EPS manufacturer was assessed as a normal level of risk at the mesoscale, both in the present and in the future (2030s and 2050s). Since the industrial park in Pyeongtaek had efficiently serviced drainage and well organized company cooperation within the industrial park, there was no flood damage risk. The flood possibility was assessed as very low, yet there was a high probability of sudden power interruption, therefore it was assessed that production would be suspended and delayed by the power failure. When aggregating the risks, the risk to the facilities by power failure was assessed as a dangerous level. Flooding of other facilities was assessed as being at a safe level and the risk of raw material and product quality deterioration by flooding was assessed as being at a normal level because the risk is small considering climate and location characteristics, but the power supply required for production is unstable during flooding. The business subject to assessment was located within the capital region where infrastructure and the surrounding areas are well equipped. Therefore, the infrastructure is well serviced against flooding but the business can be significantly affected when flooding occurs. The facilities and the power supply network therefore need to be checked regularly.

In pulp and paper manufacturing, all items were assessed as a normal level of risk. At the mesoscale, the risk of raw material and finished product flooding (Risk 1), as well as sudden power interruption (Risk 3), was assessed as a safe level, but the product quality deterioration risk by flooding was assessed as a normal level. After making a risk matrix by aggregating the risks, Risk 2 was a normal level and the other risks were assessed as a safe level. However, Ulsan area, where the pulp and paper manufacturer was located, had a high risk in the hazard assessment results as a result of precipitation. The risk at the mesoscale was assessed as medium grade considering the infrastructure and geographical conditions. When aggregating the risks, because it was assessed as being at a safe or partially dangerous level, the enterprise has a low flood risk for the near future due to the characteristics of the business type. The raw materials and finished products may be affected greatly by torrential rainfall; therefore precautions should be taken. Although the relevant business has a significant risk of rarely being operated when the industrial water supply is affected by drought, it was assessed that the flood risk would not be significant.

For the case of the power plant and the EPS manufacturer, some risk items were assessed as being at a dangerous level. Other risk items in the same power plant were assessed as a safe level, which is a result of different risks in the company and different impacts of the risk on that company. However, the consequences were assessed using mainly in-depth interview data and the assessment criteria by analyzing past flood damage cases at the business. The subjective opinions of the company officer are reflected in the determination of the risk items. However, since the results show the officer' s judgement based on previous flood damage in the business, it was determined that the assessment results reflected the actual business situation. In addition, the risks at the microscale were assessed by aggregating the probability based on actual damage cases, as well as the opinion of company officers, although the company officer judged that the impact would be small when a flood occurred. The risks were represented as high because the actual damage frequency was high. Therefore, it is expected that this study can help to reduce flood damage for this business.

The vulnerability of the power plant, EPS manufacturer, and the pulp and paper manufacturer was assessed as 4th grade; therefore, action against deterioration and flooding is required regarding the infrastructure. However, in the area where the business subject to assessment was located, the hazard ranged from 1st grade to 3rd grade. Therefore, since the probability of damage by torrential rainfall is low but the vulnerability is high, there is a normal level of risk. Since such assessment results at the mesoscale considered the entire industrial park and not the individual business, a multiscale assessment is required in order to comprehensively consider the business circumstances, in which assessment of the same rainfall event that generated the flood is possible. Therefore, this study suggests an assessment method that can assess the flood risks at one company in the case when the same rainfall event may occur on two spatial scales.

When comprehensively analyzing the risks, there was a trend for some risks to increase in the future in some businesses subject to assessment. However, on the mesoscale, most of the risks did not fluctuate significantly between the present and the future (2030s and 2050s). Since it was assumed that the vulnerable areas were the same both in the present and the future, the mesoscale impact of the weather on the risk assessment results in the future was significant. In the climate change scenario, there are diverse models and scenarios used to reduce the uncertainty in forecasting the future based on past data. However, in this study, only two scenarios: RCP 4.5 and 8.5, were considered due to a limitation in collecting the data, and only one model was used to construct the scenario; therefore, a weakness of this study was not considering the uncertainty. In the research of Kourgialas and Karatzas (2016) assessing the flood risks in Greece, the areas with a very high risk increased by −4.4 ~ 1% of the entire area, and the area with a high risk increased by 3.3% ~3%. The research of the Korea Meteorological Administration shows that (2011), for the case of RCP 4.5, the average precipitation during 2020~2049 will increase by approximately 8.4% compared to the present, and for the case of RCP 8.5, the average precipitation from

2020 ~ 2019 will increase by approximately 5.2% compared to the present. As such, due to uncertainty in forecasting the impact of climate change (Takahasi, 2013), Prime et al. (2016) argued that further related research is needed. If all of the differences in the various scenarios are considered, the range of risk can be accurately determined.

In this study, by considering the vulnerable area, including climate, sensitivity, and adaptation ability, the risks at the mesoscale were assessed. Furthermore, to assess the probable risks to business, the risks considering probabilities and the microscale impacts were assessed. As the risks were aggregated into a risk matrix, this study did not consider the impacts due to climate alone. The hazard in this study was assessed based on the index and the businesses subject to assessment; therefore, although the value of hazard did not vary greatly according to future climate change, the other factors besides climate were thoroughly considered, making it a valid study on the development of a flood risk assessment system for businesses.

At the mesoscale, the hazard and vulnerability were assessed for national industrial parks across the country, and the grade of the industrial parks where the relevant businesses were located was marked in the risk matrix by rating the hazard and vulnerability assessment results. Since flood damage in the industrial sector occurs after torrential rainfall of more than 100 mm/day, such an assessment is possible, and the mesoscale risks were assessed by aggregating the results for the present with those for the future. On the microscale, the potential risk items were determined through in-depth interviews with company officers. The degree of impact was assessed when it occurred, and the probability of the risks was assessed according to the criteria by analyzing previous damage cases in the company. Since this is the company damage based on experience of damage under extreme circumstances of torrential rainfall, it can be considered as the intensity of the risk perceived by the company officers. However, since the frequency of extreme rainfall events is not determined objectively from the interview, the frequency was assessed directly according to previous studies on the frequency and nature of actual damage. The probable risks and impacts selected by the company officers are, therefore, the actual damage felt by the business. It may be subjective but since the probability of the risk was determined from previous damage cases, the flood risk assessment results for the company were determined as objective. Therefore, it is expected that the results of this study can form the foundation for determining the degree of risk in a business.

6. Conclusion

In this study, to consider the flood risks in enterprises comprehensively, a multiscale flood risk assessment model is suggested, and its applicability is verified by applying it to the actual enterprises.

To reduce the damage to enterprises, it is necessary to identify and assess the risks precisely, assessing not only the geographical conditions according to the location, climate, and infrastructure, but also the characteristics of the business type, management, and working environment in the enterprise comprehensively. The flood risk at the mesoscale, which considers the industrial park where the enterprise is located, and in the microscale, which considers the enterprise, and the possible flood risks, were assessed comprehensively by illustrating the results with a risk matrix.

At the mesoscale, to identify the geographical and meteorological characteristics of the area where the enterprise is located and the characteristics of the infrastructure, risk was assessed using the concept of vulnerability and hazard. The rainfall pattern matched with the industry was used as an index based on the damage cost, damage area, and recovery cost of the industrial parks and enterprises after actual torrential rainfalls, and trends that were different from the flood criteria used by local government were found. In this study, the hazard was assessed considering both the intensity and frequency of rainfall, using the number of days with more than 100 mm of precipitation and the frequency of five or more consecutive rainy days occurring. To assess the area vulnerable to flooding, the areas susceptible to flooding and the areas with high adaptation ability were used as an index, and the vulnerability was assessed by excluding the areas with high adaptation ability from the susceptible areas. The assessment results were classified into five grades, and were classified as safe (1st grade), normal (2nd grade), and dangerous (3rd grade) by applying the grade of vulnerability and hazard to the risk matrix.

At the microscale, to identify the business type and individual management status, risk was assessed using the concept of probability and the consequence. After listing the potential risks that can occur in the enterprise, three risks with great impact on the enterprise were selected and assessed. The probability of the risks were assessed using five grades through the damage cases in the enterprise by torrential rainfall, inundation trace maps of the administrative district where the enterprise is located, and in-depth interviews with the enterprise officers. The impact of three risks on the enterprise was assessed using five grades based on the in-depth interviews and written interview data with the enterprise officers. The risks were classified as safe (1st grade), normal (2nd grade), and dangerous (3rd grade) by applying rated consequence and probability to the risk matrix.

To determine the flood risk in the enterprise comprehensively, the risk assessment results, which classified the risks into three grades at the mesoscale and microscale, were finally classified as safe (1st grade), normal (2nd grade), and dangerous (3rd grade) by applying them again to the risk matrix. Since it aggregates the results in the microscale and mesoscale, as it comprehensively considers the probability of climate exposure, vulnerability of the industrial park to flooding, probability of flooding in the enterprise, and the impacts, this method has the advantage of managing the flood risk due to climate change comprehensively, considering the characteristics of the area and the enterprise.

This methodology is meaningful because it considers not only the enterprise but also the environment of the area in order to assess the risks faced by enterprise. It is also meaningful because it is able to determine that industrial areas have flooding criteria that are different from those that apply to general cities. In previous studies, since it is difficult to collect and analyze the data from enterprises, research related to climate change and flood risk has been not sufficient. However, a method to assess the characteristics of enterprises and management environments comprehensively, considering future climate change in the long-term view can help to reduce losses by reducing the risk faced by enterprises. The assessment system suggested by this study is a conceptual method, which can be used for climate phenomena such as droughts as well as floods, and can be used in managing risks in enterprises.

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Summary in Korean

최근 기후변화로 인하여 도시 및 산업계에 미치는 기상재해의 피해가 증가하고 있다. 특히 집중호우로 인한 도시 및 산업시설의 침수피해는 직접적으로 국가 경제에 큰 영향을 미치며, 피해를 복구하기 위하여 많은 복구비용을 사용하게 된다. 미래 기후변화에 따라 홍수에 의한 피해가 증가할 것으로 예측되고 있기 때문에 피해 저감을 위하여 미래 기후변화에 따른 홍수피해를 정확히 평가할 수 있는 평가 방법이 필요하다.

리스크평가는 홍수 및 자연재해 등으로 인한 도시 및 기업의 피해를 사전에 대응하기 위한 평가 방법으로 주로 사용되고 있다. 실제 피해사례에 기반 하여 발생 가능한 홍수로 인한 피해를 목록화 하여 이에 대해 발생 가능성과 피해 규모로 리스크를 평가하고 있다. 이를 공간에 적용하여 취약지역에 발생하는 해저드로 리스크를 평가하기도 한다. 기존에는 도시에 대한 홍수 리스크평가, 일부 기업이 재무 재표를 이용하여 경제적 이익을 극대화 하기위해 자체적으로 리스크평가를 하고 있다. 하지만 기업이 홍수에 대한 리스크의 정도를 정확히 판단할 수 있는 평가 툴이 을 평가하기 위해서는 기업뿐만 아니라 기업이 입지한 산업단지까지 고려한 평가가 필요하다. 이는 기업이 생산활동을 하는데 공업용수 및 도로, 전기 등 인프라를 산업단지 단위로 관리하는 경우가 많기 때문이다. 따라서 이러한 측면을 고려한 종합적인 기업의 홍수 리스크평가가 필요하다.

본 연구에서는 기후변화에 따른 홍수 리스크를 평가하기 위하여 다중스케일을 고려한 리스크 평가 체계를 제시하고자 한다. 이를 위하여 첫째, 거시적 공간 범위와 미시적 공간범위를 정의하고 평가 대상 및 평가 대상의 공간범위를 설정하였다. 둘째, 각 공간단위에서의 평가 방법을 선정하

였다. 평가방법은 평가 목적 및 공간 범위에 따라 달라질 수 있으며, 거시적 스케일에서의 리스크평가는 취약성과 해저드의 개념을 이용하였고, 미시적 스케일에서의 리스크평가는 발생가능성과 발생으로 인한 영향의 개념을 이용하였다. 셋째, 현장조사, 전문가 자문, 기후변화 시나리오, 관계자와의 심층인터뷰, 실제 기업 및 산업단지 내의 홍수로 인한 피해 자료를 수집하여 데이터를 구축하였다. 거시적 스케일과 미시적 스케일에서 각각 리스크를 평가 후에 이를 리스크 매트릭스로 종합하여 최종적으로 기업의 홍수 리스크를 평가하였다. 이러한 평가 체계는 기업과 관계된 다양한 환경 및 기업의 특성을 고려하여 기업의 실제 홍수 리스크를 저감시키는 유용한 평가 툴로 사용할 수 있을 것이다.

본 연구는 다중스케일에서 홍수 리스크평가 체계를 제안하고 이를 적용하였다. 업종을 고려하여 홍수리스크 평가가 필요한 기업 4개를 선정하였다. 선정된 기업은 발전소, 전자부품제조사, EPS제조사, 펄프제지 제조사이다.

거시적 스케일에서는 지표를 기반으로 해저드와 취약성을 평가하고 등급화 후, 각 평가 결과를 리스크 매트릭스로 종합하였다. 지표는 선행연구로 목록화 하였으며, 기후변화 및 산업부문 전문가 및 기업 관계자, 기업을 관리하는 지방자치단체, 인력관리공단, 산업단지관리공단 등의 관계자에게 자문 및 심층인터뷰로 지표를 검토를 받아 평가 취약성 지표를 선정하였다. 문헌 연구 및 실제 홍수로 인한 산업단지 및 기업의 피해사례 자료를 수집하여 해저드의 평가지표를 선정하였다. 해저드와 취약성평가는 산업단지 별로 각각 5개의 등급으로 평가하였으며, 평가 결과를 리스크 매트릭스에 도식화하여 4개의 기업이 입지한 산업단지의 거시적 스케일에서의 리스크를 평가하였다. 최종 평가한 결과는 안전(1등급), 주의(2등급), 위험(3등급)으로 구분하였다. 발전소는 현재와 미래 모두 주의등급

으로 평가되었다. 전자부품제조사는 현재와 가까운 미래에 리스크가 안전등급이었으며, 2050년대에는 주의등급으로 리스크가 증가하는 것으로 분석되었다. EPS 제조사는 현재와 미래 모두 주의등급으로 평가되었으며, 펄프 및 제지 제조사도 현재와 미래 모두 주의등급으로 평가되었다.

미시적 스케일에서는 문헌연구 및 피해사례 수집 등을 통하여 홍수 리스크를 목록화 후, 평가 기업에 발생 가능한 리스크를 3개 선택하였다. 선택한 리스크에 대하여 기업 관계자와의 심층 인터뷰 및 피해자료 수집, 인근 대상지의 침수흔적도 등의 자료를 이용하여 발생가능성과 영향을 5등급으로 평가하였다. 각 평가한 결과를 리스크 매트릭스에 도식화하여 안전(1등급), 주의(2등급), 위험(3등급)으로 구분하였다. 발전소는 Risk1에 대하여 위험등급, Risk2는 주의, Risk3은 안전 등급으로 평가하였다. 전자부품제조사는 Risk1은 안전, Risk 2와 Risk 3은 주의등급으로 평가되었다. EPS제조사의 경우 Risk 1은 안전등급, Risk 2는 주의등급, Risk 3은 위험등급으로 평가되었다. 펄프제지 제조사의 경우 Risk 1,3은 안전등급, Risk 2는 위험등급으로 평가되었다. 이는 모두 현재 기업의 시설·관리의 현황을 기준으로 평가한 결과이다.

미시적 스케일과 거시적 스케일에서의 평가 결과를 다시 리스트 매트릭스에 도식화하여 종합적으로 기업의 홍수 리스크를 평가하였다. 거시적 스케일에서는 기후변화를 고려하였다. 하지만 미시적 스케일에서는 기업의 기후변화에 따른 변화를 반영하기 어려우며, 기후변화를 고려한 시설·설비에 대한 투자가 불확실하기 때문에 현재를 기준으로 평가하였다. 한번 설립된 기업이 2050년대까지 시설설비의 일부 보수 및 교체 이외에 증감이 없을 것으로 판단하였기 때문에 거시적 스케일에서의 리스크평가 결과와 미시적 스케일에서의 리스크평가 결과를 하나의 매트릭스 내에서 비교를 하였다. 따라서 거시적 스케일에서는 현재와 미래를 표시하였으

며, 각각에 대하여 미시적 스케일에서의 현재 값을 적용하였다. 발전소는 Risk1에 대하여 위험등급, Risk2는 주의, Risk3은 안전 등급으로 평가하였다. 전자부품제조사는 Risk1은 안전, Risk 2와 Risk 3은 현재에는 안전등급이지만, 미래에는 주의 등급으로 변할 것으로 평가되었다. 이처럼 기업이 현재와 동일한 기준의 홍수를 고려한 시설·설비를 가동 할 때에 미래의 기후변화에 따른 기업의 홍수 리스크 위험 정도의 변화를 확인할 수 있었다.

본 연구의 결과는 기업 관계자와의 2회 이상의 심층인터뷰와 홍수로 인한 기업의 피해사례, 기업이 입지한 지역의 피해사례, 기업과 관계된 지방자치단체 및 각종 관리기구와의 인터뷰 및 자료를 수집하여 데이터를 구축하였다. 이러한 자료는 실제 기업에 발생 가능한 홍수 리스크의 위험 정도를 종합적으로 판단하여 피해 저감에 활용하기 용이하다. 기업에서는 미래 기후변화로 발생 가능한 자연재해 대비를 위한 투자를 하기보다, 생산실적 증가를 위한 투자를 우선적으로 하기 때문에 산업과 기후변화, 특히 기업과 기후변화의 관계를 평가하는 연구가 미흡한 상황이었다. 따라서 다중스케일을 고려한 기업의 홍수 리스크평가 방법은 기업의 장기적인 측면에서의 홍수 리스크 관리에 유용하게 사용할 수 있을 것으로 기대한다.

주요어 : 리스크, 리스크평가, 리스크분석, 홍수, 산업단지, 산업, 거시적 리스크평가, 미시적 리스크평가, 다차원 리스크평가, 기업

학번 : 2011-31228

Appendix Ⅰ. Information of the Industrial parks

No.	Symbol	Name of industrial parks	Location
1	GJ	Gojung national industrial park	Boryeong city, Chungnam
2	GY	Gwangyang national industrial park	Gwangyang city
3	GSV	Gwangju Science valley	Bookgu, Gwangju city
4	GN	Gumi national industrial park	Gumi city, Gyeongsangbuk-do
5	GH	Gumi-Hightech	Gumi city, Gyeongsangbuk-do
6	GS	Gunsan national industrial park	Gunsan city, Jeollabuk-do
7	GS2	Gunsan2 national industrial park	Yeonsugu, Incheon city
8	ND	Namdong national industrial park	Dalseong-gun, Daegu
9	DS	Dalsung2 industrial park	Dalseong-gun, Daegu
10	DG	Daegu Science park	Dalseong-gun, Daegu
11	DD	Daeduck Innopolis	Yuseong-gu, Daejeon
12	DB	Daebul national industrial park	Mokpo,Jeollanam-do
13	DJ	Daejuk stock-up resources industrial park	Seosan, Chungcheongnam-do
14	MN	Myungji-Noksan national industrial park	Gangseo-gu, Pusan
15	BS	Banwol-Siwha Banwol specail zone shiwha	Siheung, Gyeonggi-do
16	BA	Banwol-Ansan Banwol specail zone Ansan	Ansan, Gyeonggi-do
17	BE	Boeun national industrial park	Boeun, Chungcheongbuk-do
18	BP	Buckpyoung national industrial park	Donghae, Gangwon-do
19	BG	Bitgreen industrial park	Hampyeong, Jeollanam-do
20	SI	Samil stock-up resources industrial park	Yeosu, Jeollanam-do
21	SM	Sseongmun national industrial park	Dangjin, Chungcheongnam-do

22	AS	Asan national industrial park	Pyeongtaek, Gyeonggi-do
23	AJ	Ahnjung national industrial park	Tongyeong, Chungcheongnam-do
24	YS	Yeosu national industrial park	Yeosu, Jeollanam-do
25	OS1	Osong bioscience industrial park	Cheongju, Chungcheongbuk-do
26	OP	Okpo national industrial park	Geoje, Chungcheongnam-do
27	OS	Onsan national industrial park	Ulju, Ulsan
28	UM	Ulsan-Mipo national industrial park	Ulsan
29	WS	Wolsung residential site	Gyeongju, Chungcheongbuk-do
30	IS	Iksan1 national industrial park	Iksan, Jeollabuk-do
31	JH	Janghang national industrial park	Seocheon, Chungcheongnam-do
32	JD	Jukdo national industrial park	Geoje, Chungcheongnam-do
33	JP	Jisepo stock-up resources industrial park	Geoje, Chungcheongnam-do
34	JH	Jinhae national industrial park	Jinhae, Chungcheongnam-do
35	CW	Changwon national industrial park	Changwon, Chungcheongnam-do
36	PB1	Paju-Bookcity	Paju, Gyeonggi-do
37	PT	Pajutanhuyng small and mid size industrial parks	Paju, Gyeonggi-do
38	PH	Pohang national industrial park	Pohang, Gyeongsangbuk-do
39	PY	Pohang Bluebelly	Pohang, Gyeongsangbuk-do
40	HB	Bupyung, Korean exporting	Bupeong-gu, Incheon
41	HS	Seoul, Korean exporting	Guro, Seoul
42	HJ	Juahn, Korean exporting	Incheon

AppendixⅡ. In-depth interview Material 1

* This material was the collected data from the Korea Energy Research agency research, 2015

(극한조건 하 설문지 작성)

1. 집중호우가 발생할 경우 에너지 사용량이 달라집니까?

( )

2. 달라질 경우, 어떤 단계에서 어떤 에너지가 추가됩니까? 혹은 절약됩니까?

( )

3. 집중호우에 따른 에너지사용량 변동이 기업에 미칠 리스크를 평가해 주십시오.

		1	2	3	4	5	
이익창출	초과달성			V			이익창출없음
안정된 수주	초과달성				V		수주목표미달
원자재 안정적 공급	안정적공급				V		공급중단
인적자원	공급원활			V			공급중단
공정준수	공정달성		V				공정중지

4. 습도 등의 변화로 인하여 설비의 출력이 달라지는 경우가 있다면 설명과 함께 리스크를 평가해 주십시오

( )

5. 수자원 공급에 영향을 받는 제품의 비율은?

( )

6. 수자원 공급에 영향을 받는 원자재의 비율은?

( )

AppendixⅡ. In-depth interview Material 2

* This material was the collected data from the Korea Energy Research agency research, 2015

◉ 설문방법

※ 설문방법 설명은 4페이지까지 계속됩니다 ※

① 설문지 배경사항

• 기후노출에 대하여 귀 사의 취약 정도 및 리스크의 강도를 평가하기 위하여 다음과 같은 설문을 수행하려 합니다.

- 본 설문에서는 '기후노출' 의 강도를 하, 중, 상으로 제시하며, 이에 대한 상세 기준은 각 설문 하는 페이지에 기술되어 있습니다. (강도기준 : 피해발생금액).

<본 설문에서의 가뭄 강도기준 예시>

기후노출의 강도	기 준
하 (下)	물 부족 시작 : 자발적 절수가 요구되는 정도
상 (上)	광범위하게 물이 부족하여 물 사용이 제한되는 정도

• 본 설문을 위해 연구진은 '가뭄' 으로 인해 발생 가능한 사건˙사고(리스크)들을 목록화 하였습니다.

- 리스크 목록은 주요 산업요소인 '물류시스템, 생산시스템, 근로자, 부지(산업단지), 금융˙시장' 으로 분류하여 목록화 하였으며, 주 산업요소의 정의는 다음 표와 같습니다.

<리스크 발생 시 영향을 받을 수 있는 주요 산업요소의 정의>

산업요소	정 의
물류시스템	도로, 철로, 항만, 공항 등을 포함한 유통 등을 의미
생산시스템	생산설비, 공업용수, 전력, 폐기물 관련시설, 생산물품의 저장 등과 관련
근로자	실내·외에서 제품을 생산하기 위한 근로자 및 관리자 관련사항
부지	산업단지의 입지적인 측면에 대한 내용
금융	기후로 인한 자연재해 등의 금전적인 피해 (보험료 등)

② 설문방법

• 설문지에서 제시되는 사건˙사고(리스트) 목록이 귀사의 산업기능에 미칠 수 있는 위험정도를 0~5점으로 응답해주십시오.

- 리스크 목록 1개당 주요 5가지 산업기능 측면의 위험정도를 0~5점으로 응답해주시기 바랍니다.
  (5가지 산업기능측면 : 이익창출, 안정된 수주, 기자재 공급, 인적자원, 공정준수)
- 발생하지 않을 가능성은 0점, 위험정도는 위험하지 않을수록 1점에 가깝게, 위험할수록 5점에 가깝게 응답하시기 바랍니다.
- 공기업의 경우, 이익창출이 목적이 아니므로, "이익창출" 과 "안정된 수주" 부분에 대해서는 0 혹은 자율적으로 판단해 주시기 바랍니다.

<위험정도를 응답하기 위한 5가지 산업기능 측면>

위험정도	이익창출	안정된 수주(주문)	기자재 안정적인 공급	인적자원	공정준수
5점 (매우 위험함)	창출없음	목표 미달성	공급 중단	인력공백	공정중지
4점 (위험함)	달성부족	목표 부족	장기 공급지연	장기부족	장기 공정정지
3점 (보통)	목표달성	목표 달성	공급지연	단기부족	공정지연
2점 (위험하지 않음)	일부 초과달성	일부 초과 달성	단기 공급지연	약간문제	단기 공정지연
1점 (매우 위험하지 않음)	초과달성	초과 달성	안정적 공급	원활	공정달성
0점	해당사항 없음				

※ 본 설문은 귀사의 ***방재대응 현재 그대로 진행 될 경우를 가정하여 각 기후노출 강도에 따라 평가해 주시기 바랍니다.***

(즉, 기후변화로 인해 해당 사건사고가 발생했을 때, 그에 대한 대응대책이 전무한 경우 귀사에 위험을 미치는 정도를 응답해주시기 바랍니다)

③ 설문지 구성

• 본 설문지는 5페이지 이후부터 구성되어있습니다.

- 설문 1) 기후노출(가뭄)에 따른 사건˙사고(리스트) 목록이 귀사의 산업기능에 미칠 수 있는 위험정도를 응답

  ※ 첫 번째 설문지 응답은 필수입니다 ※

- 설문 2) 가뭄 혹은 가뭄이외의 기후요인으로 인한 추가 피해사례 및 예측되는 리스크를 작성

2. 홍수, 집중호우, 태풍으로 인한 기업의 리스크 평가

2.1. 다음 기후노출의 기준에 따라 발생 가능한 리스크의 정도를 기입해 주십시오.

홍수 기준 "하"	홍수 기준 "중"	홍수 기준 "상"
• 강우기준 140mm 미만 • 비교적 큰 피해 없이 무리 없이 홍수 및 태풍 등이 지나가는 정도 	• 강우기준 140~200mm • 홍수 및 태풍 등으로 인한 피해가 비교적 발생하는 경우로, 피해금액이 발생하는 경우 	• 강우기준 200mm 이상 • 홍수 및 태풍 등으로 인한 피해가 매우 크게 발생하는 경우 • 만조수위와 방류시점이 겹쳐서 크게 피해가 발생하는 경우도 발생함 • 2003 태풍 매미 등과 유사한 강도의 피해 

산업기능	리스크 항목	위험한 정도 (0~5점으로 표기) 발생하지 않을 경우 0점/ 위험하지 않을수록 1점에 가깝게, 위험할수록 5점에 가깝게														
		이익창출			안정된 수주			기자재의 안정적 공급			인적지원			공정준수		
		하	중	상	하	중	상	하	중	상	하	중	상	하	중	상
물류	도로 침수 및 붕괴															
	도로 비탈면 붕괴 및 토사유출															
	태풍·폭우로 인한 운송차량 침수 및 파손															
	집중호우 발생 시 원자재 유실 및 손상															
	도로 마비															
	제품 운송시설 파손															
	침수피해로 인한 교통사고(철로·도로 등) 확률 대폭 증가															
생산	태풍으로 인한 생산시설 침수 및 파괴															
	각종 기자재 및 대형장비 파손·전복 우려															
	강풍·집중호우 등으로 인한 건축물 붕괴 가능성 증가															
	전력소·변전소 피해로 인한 전력공급 중단 (생산시스템 마비)															
	가로시설물 파손 위험 증가															
	수처리장 손상															
	홍수로 인한 오염수 유출															
	장기간 집중호우로 인해 외기온도 저하 시 온도 유지 등을 위해 추가 에너지사용량 증가															
	습도 증가로 원자재 및 최종제품 품질 저하															
	침수로 인한 폐기물의 혼합배출 가능성 증가															
	태풍·홍수로 인한 폐기물 처리시설의 손상 및 붕괴															
근로자	시설물 붕괴 및 감전사 등 근로자 사망률 증가															
	낙뢰 등으로 인한 부상 대폭 증가															
	근로자 정신건강(외상 후 스트레스 등) 장애 발생 가능성															
	실외근로자 업무 불가능															
부지	만조수위와 겹칠 경우, 홍수피해 확률 증가															
	내수배제 시설의 노후화로 인한 피해확률 대폭 증가															
	사업장 내부 및 인근 해안의 범람확률 대폭 증가															
금융	홍수에 대한 인적·물적 보험료 상승															
	피해시설 복구비용 증가															
	기반시설 수급차질로 인한 수송비용 추가발생															
	물량 미공급 등 손해배상청구비용 발생															
시장	제품생산과 관련된 타기업의 연쇄 피해발생 가능성 대폭 증가															
	생산제품 품질 저하															

AppendixⅢ. The lists of data

Data	Context	Sources
Climate change scenarios	RCP4.5,8.5 HadGEM3RA model (accumulated data 400 years)	Korea Meteorological Administration Web-site
DEM, Slope	Digital map	National geographic information institute
Inundation trace map	Inundation trace map	Local autonomous entity
Soil map	Drainage classes	Soil and environmental information system of korea
Boundary of industrial parks	Boundary of industrial parks	Korea industrial complex corporation
Status of Industrial parks	Information of infrastructure about each industrial parks	Korea industrial complex corporation
Land cover	green space area Impervious area ratios	Ministry of environment
Flood reduction facilities	Flood mitigation facilities capacity	Interview of local government officials